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NASA Project Mercury Working Paper No. 230

PROJECT MERCURY

POSTLAUNCH TRAJECTORY REPORT FOR MERCURY-ATLAS MISSION NO. 4 (MA-4) (SPACECRAFT 8A - ATLAS 88-D) AND FOR MERCURY-ATLAS MISSION NO. 5 (MA-5) (SPACECRAFT 9 - ATLAS 93-D)

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

OCTOBER 1962

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PROJECT MERCURY

POSTLAUNCH TRAJECTORY REPORT FOR MERCURY-ATLAS MISSION NO. 4 (MA-4) (SPACECRAFT 8A - ATLAS 88-D) AND FOR MERCURY-ATLAS MISSION NO. 5 (MA-5) (SPACECRAFT 9 - ATLAS 93-D)

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1.0 INTRODUCTION

This report summarizes and documents the final trajectory data for the MA-4 and MA-5 missions. Included are the actual trajectory data, Mercury Control Center, Range Safety and Remote Site plotboard displays, that the controlling and monitoring personnel used to evaluate the performance of the launch vehicle and spacecraft, and to exercise their command functions during the missions. This report includes some of the data given in reference 1 and 2 as well as other data not available at that time.

2.0 MA-4 EVENTS, TRAJECTORY, AND GUIDANCE

2.1 Sequence of events. - The times at which the major events occurred are given in table 1.

2.2 Trajectory. - The ground track of the flight is shown in figure 1, and the altitude-longitude profile is shown in figure 2.

The launch trajectory data, shown in figure 3, are based on the real-time output of the Range Safety Impact Predictor Computer (which used AZUSA MK II, and Cape and Patrick FPS-16 radars) and the G.E.-Burroughs guidance computer. The data from these tracking facilities were used during the time periods listed below:

Facility	Time, Min:Sec
FPS-16 (Cape 1.16 and Patrick I.P. 16)	0 to 00:55
AZUSA MK II	00:55 to 01:15
G. E.-Burroughs	01:15 to 05:02

The parameters shown for the planned launch trajectory were computed using the 1959 ARDC model atmosphere for consistency with other published trajectory documents. The density of the Cape Canaveral atmosphere is approximately 10 percent higher than that of the 1959 ARDC atmosphere in the region of maximum dynamic pressure (about 37,000 ft. altitude); as a result, the maximum dynamic pressure experienced was about 10 percent higher than that shown as "planned."

The orbital portion of the trajectory, shown in figure 4, was obtained by starting with the capsule position and velocity vector near Muchea (as determined by the Goddard computer using radar data from Bermuda, Grand Canary Islands, and Muchea) and integrating backward along the flight to orbital insertion and forward along the flight to the start of retrofire. These integrated values were in good agreement with G.E.-Burroughs guidance system measured values at orbital insertion, one ft/sec in velocity and .03 degrees in flight-path angle, thus establishing the validity of the integrated orbital portion of the trajectory.

The reentry portion of the trajectory, shown in figure 5, was obtained by starting with the capsule position and velocity

vector near Eglin as determined by the Goddard computer (using radar data from Eglin and Corpus Christi) and integrating backward along the flight to the end of retrofire and forward along the flight to landing. These integrated values at the end of retrofire were adjusted by adding the effects of a nominal retrorocket total impulse of 38,880 lb-sec at nominal capsule attitudes of -34° pitch with zero roll and zero yaw, and the results were in good agreement with the orbital integrated values at the start of retrofire. The capsule accelerations from the integrated trajectory agree within reading accuracy with the accelerations measured by the capsule onboard accelerometer; in addition, the times of 0.06g and drogue parachute deployment from the integrated reentry trajectory and from capsule onboard measurements agree within 1 second. This agreement between integrated values and independently measured values onboard the capsule serves to verify the validity of the integrated reentry portion of the trajectory. The aerodynamic parameters for the planned and integrated reentry trajectories were computed using the STG model atmosphere (NASA Project Mercury Working Paper No. 205) which is based on Discoverer Satellite Program data above 50 n.m. altitude, the 1959 ARDC model atmosphere between 25 n.m. and 50 n.m. altitudes, and the Patrick AFB atmosphere below 25 n.m. altitude.

In the trajectory figures the above integrated values are labeled "actual."

A comparison of the planned and actual trajectory parameters is given in table 2. The differences between the planned and actual trajectory parameters are due to the actual cutoff velocity and flight-path angle being lower than the planned conditions.

2.3 Guidance. - The G.E.-Burroughs Atlas guidance system guided the vehicle to an acceptable orbit; however, the performance near SECO (sustainer engine cutoff) was marginal because of excessive noise in the data. The guidance system locked on the vehicle at 62 seconds. The heading angle of the vehicle, after the programed roll maneuver, was about 1.5 degrees north of the planned heading angle (see figure 3 (b)). G.E.-Burroughs guidance steering was initiated as planned after staging, and this 1.5 degree heading angle error was corrected. In figures 6 to 8, the velocity and flight-path angle are shown in the region of SECO.

G.E.-Burroughs data are shown in figure 6 and the data used in the Range Safety Impact Predictor Computer (IP 7090) are shown in figure 7 to illustrate the noise level during the time of

GO/NO-GO computations. Both the GE and the AZUSA data were very noisy. The noise in the GE guidance data was more than 5 times higher than expected, resulting in a guidance cutoff which was about 20 ft/sec low in velocity and about 0.11 degrees low in flight-path angle (see figure 8). Expected guidance cutoff would result in differences from nominal of the order of 5 ft/sec in velocity and about .05 degrees in flight-path angle. In figure 4.3-3 these data are shown as flight-path angle versus velocity. This is the type of display used by the Flight Dynamics Officer in the Mercury Control Center for the orbital GO/NO-GO decision. The G.E.-Burroughs data after thrust tail-off are almost entirely in the GO region whereas much of the AZUSA data are in the NO-GO region.

3.0 MA-4 TRAJECTORY AND DISPLAY DATA

3.1 MA-4 pitch attitude. - The actual and nominal pitch attitudes during the launch phase from lift-off to capsule separation of the MA-4 mission are presented in Figure 17. The actual pitch attitude was obtained from the output of the pitch gyro which was recorded on the on-board capsule tape. The pitch attitude for MA-4 compared favorably with the planned until 00:04:10, at which time the actual pitch attitude differed by a magnitude of approximately 10 degrees from the nominal.

3.2 MA-4 Mercury control center plotboards. - During the Mercury mission, radar and telemetry data concerning the capsule are processed to derive and display in real-time the quantities which will enable controlling and monitoring personnel to evaluate the performance of the vehicle during the mission and exercise their command functions.

During the launch phase there are four plotboards (IA, IIA, IIIA, IVA) used for real-time trajectory display in the Mercury Control Center. The plotboards are presented in figure 18 for the MA-4 flight where the actual and the nominal trajectory data were displayed. The plotboards for the launch phase are based on the real-time output of the Range Safety Impact Predictor Computer (which used AZUSA MK II and Cape and Patrick FPS-16 radars) and the G.E.-Burroughs guidance computer, which transmits the position and velocity vectors to the Goddard IBM 7090 computer. The launch computations are then made in essentially real-time (there is some transmission and computing delay) and transmitted to the Mercury Control Center plotboards and digital displays.

The actual average insertion (SECO) velocity was 20 ft/sec lower, and the average flight-path angle was about .11 degrees lower than the nominal cutoff. As a result, figure 18 shows that the actual plotboard parameters are slightly displaced from the nominal. Plotboard IA shows that the velocity ratio versus flight-path angle was noisy from V/V_R of .75 to the GO/NO-GO line.

There are four plotboards (IB, IIB, IIIB, IVB) used for real-time trajectory display in the Mercury Control Center during the orbit phase based on the position and velocity vectors of the radar stations of the Mercury Network. The plotboards are presented in figure 19. The actual plotboard parameters during the orbit agreed closely with the nominal.

[redacted]

3.3 MA-4 range safety plotboards. - The purpose of all Range Safety operations is to minimize the possibility of a missile impacting outside the designated range safety limits. Of prime importance is the display and plotting equipment which provides a visual indication of the missile position, heading, and predicted impact coordinates. The missile position is projected into three planes, the ground plane (X, Y), (latitude and longitude), and two vertical planes (X, H) and (Y, H). As soon as the projection of the trajectory parallels neighboring range safety lines or the impact predicted points fall beyond the destruct lines, flight termination action is taken.

As a matter of interest, Range Safety plotboards for the MA-4 mission are presented in Figure 22. These plotboards were based on the real-time Range Safety Impact Prediction Computer which used the AZUSA MK II and FPS-16 radar tracking data. These figures show the closeness of the actual trajectory and the nominal trajectory. Figure 22 (c) shows the area displayed on the Range Safety Plotboard for impact predictions. The same plotboard displays were used on the MA-5 mission, and the data were similar.

3.4 Capsule attitude during retrofire. - Time histories of capsule pitch, yaw, and roll attitudes during retrofire for the MA-4 mission, as obtained from the capsule on-board tape, are presented in Figure 26.

The nominal attitudes for MA-4 were a 34 degree pitch with zero yaw and roll (the retrofire times are shown on the figure). Reference 4 gives the effect of attitude errors on the landing point.

3.5 Measured wind profile. - Figure 28 shows the altitude from zero to approximately 100,000 feet versus wind direction and wind speed as obtained from rawinsonde measurements in the launch area for the MA-4 mission.

3.6 MA-4 capsule impact point. - The planned impact position for the MA-4 primary landing area (end of first orbit) was 32°02'N and 60°38'W based on a nominal retrofire elapse time of 01:28:59. The insertion conditions for the MA-4 mission were not exactly nominal and this caused a slightly different than nominal orbit. This new orbit required that the retrofire elapse time be corrected by an increase of nine seconds to land at the planned impact position. However, the MA-4 missions rules state that, if the retrofire correction time to land at the planned impact point did not exceed ±15 seconds, the retro clock would not be changed from the nominal setting. Therefore,

[redacted]

the new predicted landing point based on the actual retrofire elapse time of 01:29:00 (telemetry information) was 32°10'N and 61°18'W. The actual landing point was reported as 32°08'N and 61°53'W by the recovery ship one hour and twenty-two minutes after landing and 32°09'N and 61°53'W as determined by the trajectory integration based on the Eglin position and velocity vector during reentry.

A study was made to determine the possible causes why the actual landing point was thirty nautical miles short of the predicted landing point. The major causes of error were capsule weight, capsule attitude during retrofire, and retro performance.

The actual weight loss of hydrogen peroxide from insertion to retrofire was thirteen pounds, and the nominal weight loss used in computations was six pounds. The weight difference caused an impact error (32°11'N and 61°24'W) of five nautical miles short of the nominal landing point.

The actual capsule attitude (figure 26) as compared to the nominal capsule attitude caused an additional impact (32°11'N and 61°40'W) error of fourteen nautical miles short. The latest preflight retrothrust information indicated a thrust greater than the nominal thrust. This greater thrust during retrofire caused an additional impact (32°14'N and 62°11'W) error of twenty-six nautical miles short. The above mentioned resulted in a corrected impact point which was fifteen nautical miles short of the actual impact point. The impact positions are labeled and presented in figure 30.

The fifteen nautical mile difference between the actual impact and the impact point corrected for capsule weight, attitudes, and retrothrust can possibly be attributed partly to a greater retrothrust performance used in this analysis then what actually occurred, and partly to winds in the recovery area and drift of capsule while in the water for one hour and twenty-two minutes. A study was made to determine what effect the retrothrust had on changing the impact point. The results of the study showed that one percent change in the thrust of the retrorockets changed the impact by eighteen nautical miles.

4.0 MA-5 EVENTS, TRAJECTORY, AND GUIDANCE

4.1 Sequence of events. - The time at which the major events occurred are given in table 3.

4.2 Trajectory. - The ground track of the flight is shown in figure 9 and the altitude-longitude profile is shown in figure 10.

The launch trajectory data, shown in figure 11, are based on the real-time output of the Range Safety Impact Predictor Computer (which used AZUSA MK II and Cape FPS-16 radars) and the G.E.-Burroughs guidance computer. The data from these tracking facilities were used during the time periods listed below:

Facility	Time, Min:Sec
Cape Canaveral FPS-16	0 to 00:53
AZUSA MK II	00:53 to 01:07
G.E.-Burroughs	01:07 to 05:03

The parameters shown for the planned launch trajectory were computed using the 1959 ARDC model atmosphere for consistency with other published trajectory documents. The density of the Cape Canaveral atmosphere is approximately 10 percent higher than that of the 1959 ARDC atmosphere in the region of maximum dynamic pressure (about 37,000 feet altitude); as a result, the maximum dynamic pressure expected would be about 10 percent higher than that shown as "planned." For this flight, the maximum dynamic pressure experienced was about 15 percent higher than that shown as "planned."

The orbital portion of the trajectory, shown in figure 12, was obtained by starting with the spacecraft position and velocity vector during the first pass near Muchea as determined by the Goddard computer (using radar data from Bermuda, Grand Canary Islands, and Muchea) and integrating backward along the flight to orbital insertion and forward along the flight to the start of retrofire at the end of the second orbit. These integrated values were in good agreement with the G. E.-Burroughs guidance system measured values at orbital insertion, one ft/sec in velocity and .04 degrees in flight-path angle, and also in excellent agreement with position and velocity vectors determined by the Goddard computer for passes near Eglin during the first pass (end of the first orbit and beginning of the second orbit), Muchea during the second pass (second orbit), and Hawaii during

second orbit, thus establishing the validity of the integrated orbital portion of the trajectory.

The reentry portion of the trajectory, shown in figure 13, was obtained by starting with the spacecraft position and velocity vector near Eglin as determined by the Goddard computer and integrating backward along the flight to the end of retrofire and forward along the flight to landing. These integrated values at the end of retrofire were adjusted by adding the effects of a nominal retrorocket total impulse of 38,880 lb-sec at nominal spacecraft attitudes of -32° pitch (for this particular spacecraft) with zero roll and zero yaw, and the results were in good agreement with the orbital integrated values at the start of retrofire. The spacecraft accelerations from the integrated reentry trajectory agree within reading accuracy with the accelerations measured by the onboard accelerometer; in addition, the times of 0.05 g and drogue chute deployment from the integrated reentry trajectory and from spacecraft onboard measurements agree within 1 and 2 seconds, respectively. This agreement between integrated values and independently measured values onboard the spacecraft serves to verify the validity of the integrated reentry portion of the trajectory. The aerodynamic parameters for the planned and integrated reentry trajectories were computed using the MSC model atmosphere (NASA Project Working Paper No. 205) which is based on Discoverer Satellite program data above 50 nautical mile altitude, the 1959 ARDC model atmosphere between 25 and 50 nautical mile altitudes, and the Patrick AFB atmosphere below 25 nautical mile altitude.

In the trajectory figures the above integrated values are labeled "actual."

A comparison of the planned and actual trajectory parameters is given in table 4. The differences between the planned and actual trajectory parameters are due to the actual cutoff velocity and flight-path angle being lower than the planned conditions.

4.3 Guidance.- The G.E.-Burroughs Atlas guidance system guided the vehicle to an acceptable orbit. The performance of the guidance system near sustainer engine cutoff was marginal for the 88-D (MA-4), flight due to excessive noise in the data. However, for this flight, 93-D (MA-5), the amplitude of the noise variations appeared to be about half that experienced on 88-D (MA-4) for the same elevation angles. The guidance system locked on the vehicle at 00:67 and lost lock at 05:41 (41 seconds after SECO). As in the MA-4 flight, the heading angle of the vehicle, after the programed roll maneuver, was about

1.5 degrees north of the planned heading angle. G.E.-Burroughs guidance steering was enabled as planned at 155 seconds after liftoff and this 1.5 degree heading angle error was corrected. In figures 14 and 16, the velocity and flight-path angle are shown in the region of cutoff. G.E.-Burroughs data are shown in figure 14 and the data used in the Range Safety Impact Predictor Computer (IP 7090) are shown in figure 15 to illustrate the noise level during the time of the GO/NO-GO computations. Both G.E.-Burroughs and AZUSA data showed noisy variations in the data; however, the variation in the noise for this flight was approximately half that experienced for the 88-D (MA-4) flight.

The G.E.-Burroughs guidance system gave a cutoff which was about 9 ft/sec low in velocity and about 0.07 degrees low in flight-path angle (see table 4). Expected guidance cutoff would result in differences from nominal of the order of 5 ft/sec in velocity and about .05 degrees in flight-path angle. In figure 6 these data are shown as flight-path angle versus velocity. This is the type of display used by the Flight Dynamics Officer in the Mercury Control Center for the orbital GO/NO-GO decision. Both the G.E.-Burroughs and AZUSA data after thrust tailoff are in the GO region.

5.0 MA-5 TRAJECTORY AND DISPLAY DATA

5.1 <u>MA-5 pitch attitude</u>.- The actual and nominal pitch attitudes during the launch phase from lift-off to spacecraft separation of the MA-5 mission are presented in Figure 25. The actual pitch attitude was obtained from the output of the pitch gyro which was recorded on the on-board spacecraft tape. The actual pitch attitude for MA-5 compared favorably with the planned. At BECO the actual pitch attitude differed by a magnitude of one degree, two degrees at tower separation, and three degrees at spacecraft separation from the nominal pitch attitude.

5.2 <u>MA-5 Mercury control center plotboards</u>.- Real-time trajectory display plotboards for the launch phase and orbit phase for the MA-5 flight are presented in Figures 20 and 21, respectively. The actual insertion (SECO) conditions agreed closely with the nominal; thereby, the actual plotboard parameters were close to the nominal as seen in Figures 20 and 21.

5.3 <u>MA-5 remote site plotboards</u>.- Plotboards of the remote site stations of Guaymas, California, and Texas are enclosed as a representation of all remote site stations that have radar display facilities. The plotboards display radar-centered Cartesian coordinates on a spherical earth surface. The Cartesian coordinates are true height (H), east-west ground range (X) and north-south ground range (Y). The actual and nominal display of data for Guaymas, California, and Texas for the MA-5 mission are presented in Figure 23.

In Figure 23 (a), the first orbit, first pass for Guaymas, the noise level and elevation servo problem caused the actual X, H curves to be displaced from the nominal by approximately 3 to 4 miles.

The (X, Y) actual curve was very close to the nominal. In Figure 23 (b), the first orbit, first pass for the Texas station, the actual X, Y curve was close to the nominal and the actual X, H curve did not coincide with the nominal because it did not have the earth curvature correction.

In Figure 23 (c), the second orbit reentry for the California station, the actual X, Y curve was close to the nominal, and the actual X, H curve crossed the nominal (orbit pass curve) because the H scale was different from the nominal and also the capsule was reentering. For a brief outline of all MA-4 and MA-5 plotboards, refer to Table 5.

5.4 MA-5 sighting data (R, A, E). - Sighting data for the radar, command, and telemetry stations are presented as time histories of azimuth angle, elevation angle, and slant range to assist the various stations in acquiring the spacecraft so the stations can perform their tracking, monitoring, and command functions. These data are calculated for all stations prior to launch (reference 3).

The actual and the nominal sighting data (RAE) for the Canary Islands, Muchea, Guaymas, and Bermuda radar stations for the first and second orbits are shown in Figure 24 as a representation of the world-wide Mercury Network. It can be seen in Figure 24 that the actual (real-time acquisition data) sighting data agrees favorably with the nominal.

5.5 MA-5 spacecraft attitude during retrofire. - Time histories of spacecraft pitch, yaw, and roll attitudes during retrofire for the MA-5 mission as obtained from the spacecraft on-board tape are compared with the nominal attitudes in Figure 26. The nominal attitudes for MA-5 were a -32 degree pitch with zero yaw and roll (the retrofire times are shown on the figure). Reference 5 gives the effect of attitude errors on the landing point.

5.6 Measured wind profile. - Figure 29 shows the altitude from zero to approximately 100,000 feet versus wind direction and wind speed as obtained from rawinsonde measurements in the launch area for the MA-5 mission.

5.7 MA-5 spacecraft impact point. - The impact point for MA-5 at the end of the second orbit was 28°49'N and 66°00'W based on a nominal retrofire time of 03:00:04. The insertion conditions were not exactly nominal, therefore changing the nominal orbit slightly. As a result of the new orbit, the retrofire elapse time was changed to 03:00:15 to land at the predicted impact position of 28°54'N and 66°00'W. The actual landing point was 29°02'N and 65°57'W as reported by the recovery ship one hour and twenty-six minutes after spacecraft landing, and 28°57'N and 66°04'W as determined from the trajectory integration based on the Eglin position and velocity vector during reentry.

A study was made to determine the errors in the impact point caused by the incorrect spacecraft weight as a result of the actual hydrogen peroxide used during the MA-5 two orbit mission and the attitude (pitch and yaw) errors during retrofire. The weight loss of hydrogen peroxide for two orbits used for computation was eleven pounds, and the actual weight loss was seventeen pounds. Using the actual spacecraft weight, an impact of 29°55'N and 66°03'W resulted from the trajectory integration

which landed five nautical miles short of the actual impact point. Using the actual spacecraft attitude (Figure 27) an impact position of 28°02'N and 66°19'W resulted from the trajectory integration which corrected the predicted impact in latitude but fell twenty nautical miles short of the actual impact (recovery ship) point.

The impact points are labeled and presented in Figure 30.

The difference of twenty nautical miles can possibly be attributed to retrothrust performance, the effect of the wind on the spacecraft during reentry and the drift of the spacecraft while in the water for one hour and twenty-six minutes. It was found that one percent error in the thrust of the retrorockets would change the impact point by eighteen nautical miles. It is considered that the weight and the attitude errors were compensated mainly by the retrothrust performance.

6.0 REFERENCES

1. Postlaunch Memorandum Report for Mercury-Atlas No. 4 (MA-4), NASA Space Task Group, Cape Canaveral, Florida, October 7, 1961

2. Postlaunch Memorandum Report for Mercury-Atlas No. 5 (MA-5), NASA Manned Spacecraft Center, Cape Canaveral, Florida, December 6, 1961

3. Staff of the NASA Space Task Group, Flight Operations Division, Mercury Data Coordination Office: MA-5 Data Acquisition Plan, October 1961

4. NASA Project Mercury Working Paper No. 204, PROJECT MERCURY CALCULATED PREFLIGHT TRAJECTORY DATA FOR MERCURY-ATLAS MISSION NO: 4 (MA-4) STG, Langley Field, Va., August 2, 1961

5. NASA Project Mercury Working Paper No. 207, PROJECT MERCURY CALCULATED PREFLIGHT TRAJECTORY DATA FOR MERCURY-ATLAS MISSION NO: 5 (MA-5) STG, Langley Field, Va., October 19, 1961

TABLE I. - MA-4 SEQUENCE OF EVENTS

Event	Planned Time[b] hr:min:sec	Actual Time hr:min:sec	Difference seconds
Booster engine cutoff	00:02:11	00:02:08.5	-2.5[c]
Tower release	00:02:34	00:02:32.0	-2.0
Escape rocket	00:02:34	00:02:32.0	-2.0
Sustainer engine cutoff discrete	--------	00:04:53.8	----
Tail-off complete (0.2g)	00:05:05.53	00:04:55.8	-9.73[c]
Capsule separation	00:05:06	00:04:57.2	-8.8
Initiation of retrofire sequence by clock	01:28:59	01:29:00.0	+1.0
Retro (left) No. 1	01:28:59	01:29:00.0	+1.0
Retro (bottom) No. 2	01:29:04	01:29:05.0	+1.0
Retro (right) No. 3	01:29:09	01:29:09.8	+0.8
Retroassembly jettison	01:29:59	01:29:59.4	+0.4
Begin ionization "blackout"	01:35:51	01:36:59	68.0
0.05g relay	01:38:00	01:37:24.8	-35.2 (-0.4)[a]
End ionization "blackout"	01:41:12	01:40:34	-38.0
Drogue deploy	01:43:00	01:42:21.8	-38.2 (-0.8)[a]
Main deploy	01:44:35	01:43:52.9	-42.1 (-4.5)[a]
Main chute jettison (water impact)	01:49:35	01:49:20.3	-14.7 (+19.9)[a]

[a]The numbers in parentheses show the difference between actual event time and the postflight-calculated event times based on actual insertion parameters.

[b]Preflight calculated, based on nominal Atlas performance.

[c]The maximum expected variations in time from nominal are of the order of ±2 seconds for the booster engine cutoff and ±10 seconds for sustainer engine cutoff.

TABLE 2. - MA-4 COMPARISON OF PLANNED AND ACTUAL TRAJECTORY PARAMETERS

Condition and Quantity	Planned	Actual	Difference
Cutoff Conditions (including tailoff):			
Range time, seconds	305.53	295.80	-9.73
min:sec	05:05.53	04:55.8	
Geodetic latitude, deg North	30.4368	30.4512	0.0144
Longitude, deg West	72.4801	72.8194	0.3393
Altitude, feet	528,506	527,084	-1422
nautical miles	87.0	86.8	-0.2
Range, nautical miles	438.9	422.0	-16.9
Inertial velocity, feet per second	25,695	25,675	-20.0
Inertial flight path angle, deg	0.0	-0.114	-0.114
Inertial heading angle, deg east of North	77.5088	77.3635	-0.1453
Orbit Parameters:			
Perigee altitude, statute miles	100.1	98.9	-1.2
nautical miles	87.0	85.9	-1.1
Apogee altitude, statute miles	154.7	142.1	-12.6
nautical miles	134.3	123.3	-11.0
Period, min:sec	88:34	88:19	-00:15
Inclination angle, deg	32.52	32.57	0.05
Maximum Conditions:			
Altitude, statute miles	154.7	142.1	-12.6
nautical miles	134.3	123.3	-11.0

TABLE 2.- (Concluded)

MA-4 COMPARISON OF PLANNED AND ACTUAL TRAJECTORY PARAMETERS

Condition and Quantity	Planned	Actual	Difference
Maximum Conditions: (continued)			
Space-fixed velocity, ft/sec	25,719	25,705	-14.0
Earth-fixed velocity, ft/sec	24,402	24,389	-13.0
Exit acceleration, g	7.6	7.6	0
Exit dynamic pressure, lbs/ft^2	*964 **870	975	+11.0 +105.0
Entry deceleration, g	7.6	7.7	+0.1
Entry dynamic pressure, lbs/ft^2	407	411	+4.0

*Based on Cape Canaveral atmosphere.

**Based on 1959 ARDC model atmosphere.

TABLE 3.- MA-5 SEQUENCE OF EVENTS

Event	Planned Time[a] hr:min:sec	Actual Time hr:min:sec	Difference seconds
Booster-engine cutoff	00:02:11.4	00:02:10.2	-1.2
Tower release	00:02:34.2	00:02:33.8	-0.4
Escape-rocket firing	00:02:34.2	00:02:33.8	-0.4
Sustainer-engine cutoff discrete		00:05:00.4	
Tail-off complete	00:05:04	00:05:02	-2.0
Capsule separation	00:05:05	00:05:02.9	-2.1
Retrofire initiation (two orbit mission)	03:00:04	03:00:15	+11.0
Retro (left) No. 1	03:00:04	03:00:15	+11.0
Retro (bottom) No. 2	03:00:09	03:00:20	+11.0
Retro (right) No. 3	03:00:14	03:00:25	+11.0
Retroassembly jettison	03:01:04	03:01:14	+10.0 (+1.0)[b]
Begin ionization "blackout"	03:09:17	03:08:59	-18.0
0.05 g relay	03:09:57	03:09:41	-16.0 (+1.0)[b]
End ionization "blackout"	03:13:27	03:13:16	-11.0
Drogue chute deploy	03:15:54	03:15:36	-18.0 (-2.0)[b]
Main chute deploy	03:16:31	03:16:09	-22.0 (+1.0)[b]
Main chute jettison (water impact)	03:21:19	03:20:59	-20.0 (+1.0)[b]

[a]Preflight calculated, based on nominal Atlas performance.

[b]The numbers in parentheses show the difference between the actual event and the postflight-calculated reentry event time based on actual insertion parameters.

TABLE 4.- MA-5 COMPARISON OF PLANNED AND ACTUAL TRAJECTORY PARAMETERS

Condition and Quantity	Planned	Actual	Difference
Cutoff Conditions (including tailoff):			
Range time, seconds	304.0	302.0	-2.0
min:sec	05:04	05:02	-:02
Geodetic Latitude, deg North	30.4280	30.4597	0.0317
Longitude, deg West	72.5235	72.4940	-0.0295
Altitude, feet	528,496	527,152	-1344.0
nautical miles	87.0	86.8	-0.2
Range, nautical miles	436.6	438.5	1.9
Space-fixed velocity, feet per sec	25695.0	25686	-9.0
Space-fixed flight path angle, deg	-0.0002	-0.0674	-0.0672
Space-fixed heading angle, deg east of north	77.4863	77.4398	-0.0465
Orbit Parameters:			
Perigee altitude, statute miles	100.1	99.5	-0.6
nautical miles	87.0	86.5	-0.5
Apogee altitude, statute miles	153.8	147.4	-6.4
nautical miles	133.4	128.0	-5.4
Period, min:sec	88:34	88:26	-00:08
Inclination angle, deg	32.52	32.56	0.04
Maximum Conditions:			
Altitude, statute miles	153.8	147.4	-6.4
nautical miles	133.4	128.0	-5.4
Space-fixed velocity, ft/sec	25717	25710	-7.0
Earth-fixed velocity, ft/sec	24400	24393	-7.0
Exit acceleration, g's	7.7	7.7	0.0
Exit dynamic pressure, lbs/ft^2	*966	1012	46.0
	**878		134.0
Entry deceleration, g's	7.6	7.7	0.1
Entry dynamic pressure, lbs/ft^2	438	444	6.0

*Based on Cape Canaveral atmosphere.

**Based on 1959 ARDC model atmosphere.

TABLE 5.- REMOTE SITE PLOTBOARDS FOR MA-4 AND MA-5

1. Remote site plotboards for MA-4 and MA-5 were reproduced and evaluated for their adequacy of information. The reproductions were satisfactory for most plotboards; however, some data could have been obscured by reproduction contrast or folds in the original plotboards. This concerns only the plotboards received which may or may not be all of the remote site plotboards.

2. MA-4

a. Bermuda: FPS-16 - no data obtained
VERLORT - no reentry data. Some launch data was obtained, but the xh plot was noisy and both plots had periodic acquisition losses. Conclusion: poor quality.

b. Canary Islands: Shortly after acquisition pen drift occurred during a period of invalid track. After valid track, the plot was satisfactory. Conclusion: satisfactory.

c. Muchea: The xy plot was satisfactory but the xh was somewhat noisy. Two momentary fades occurred and the pens began to drift until the signal returned. Conclusion: barely satisfactory.

d. Guaymas: The radar did not track.

e. Point Aguello, Cal: Only the xy plot was presented, but there were no zero points or scales given. Conclusion: unsatisfactory.

f. South Texas: No scales were given and there was very little valid track. Conclusion: unsatisfactory.

3. MA-5

a. Bermuda: FPS-16
First orbit - both plots were satisfactory.
Second orbit - both plots were satisfactory, but xh was a little noisy.

Reentry - no data obtained.

TABLE 5 (Concluded)

REMOTE SITE PLOTBOARDS FOR MA-4 AND MA-5

VERLORT -

First orbit - the xy plot was satisfactory, but the xh had noise. Radar lost acquisition twice. Conclusion: poor.

Second and third orbit - same comment as above.

Reentry - no data obtained.

b. Canary Islands:

First orbit - xy plot was satisfactory, but xh was unsatisfactory due to step track indication. Conclusion: poor.

Second orbit - xy plot was satisfactory, but there was no signal trace of xh. Conclusion: poor.

c. Muchea: First orbit - plots were noisy and could not be distinguished in the reproduction. There was an inadequate explanation of notations and no labeling. Conclusion: unsatisfactory.

Second orbit - both plots were satisfactory, but xh was a little noisy.

d. Guaymas: First orbit - xy plot was satisfactory but xh was somewhat noisy and had range perturbations on it. No data was lost though. Conclusion: satisfactory.

e. Point Aguello:

First orbit - no radar plot data.

Second orbit reentry - both plots were satisfactory but xh was a little noisy.

f. South Texas:

First orbit - xy plot was satisfactory but xh had some noise.

g. Hawaii: Second orbit - xy plot was satisfactory, but xh was very noisy and could not be used. Conclusion: poor.

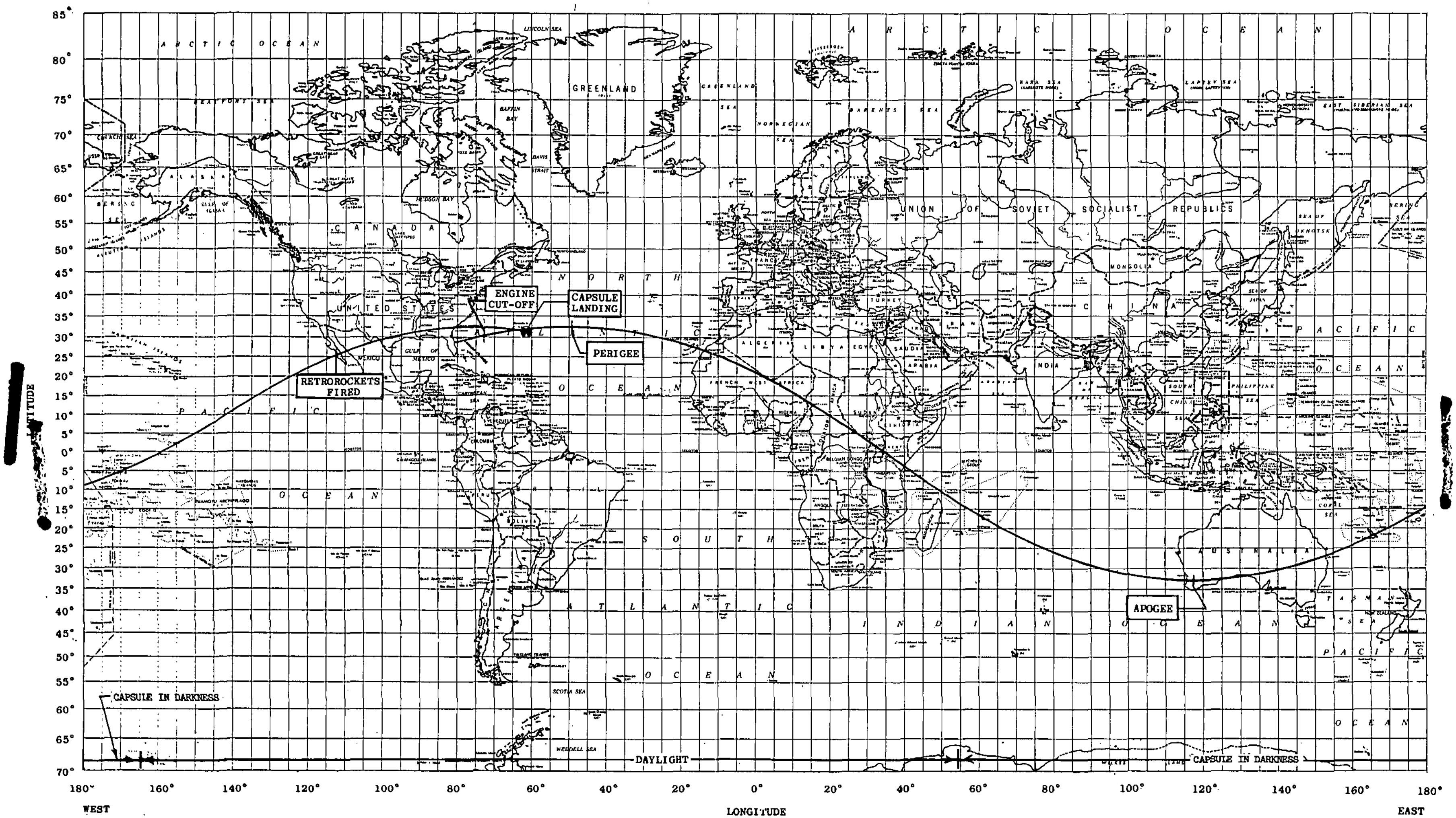


Figure 1. - GROUND TRACK FOR THE MA-4 ORBITAL MISSION.

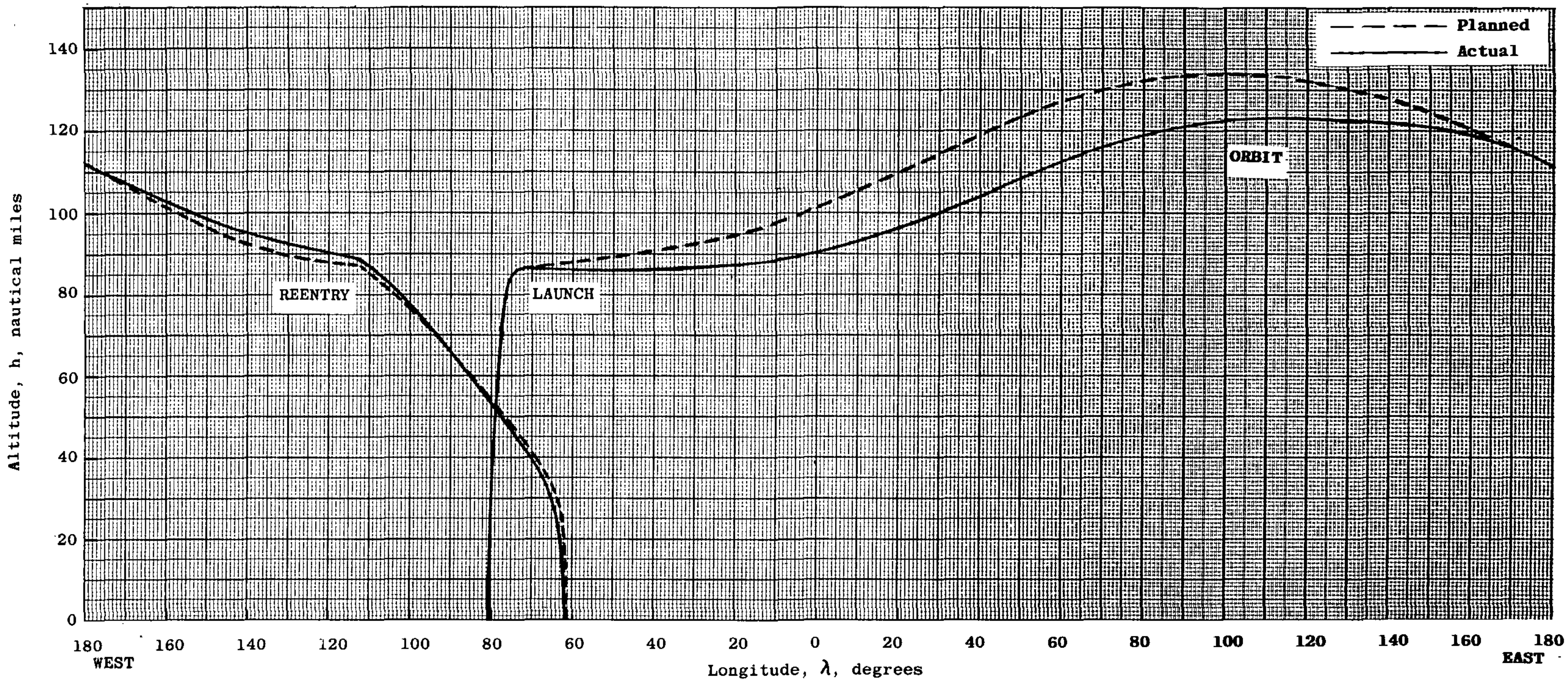
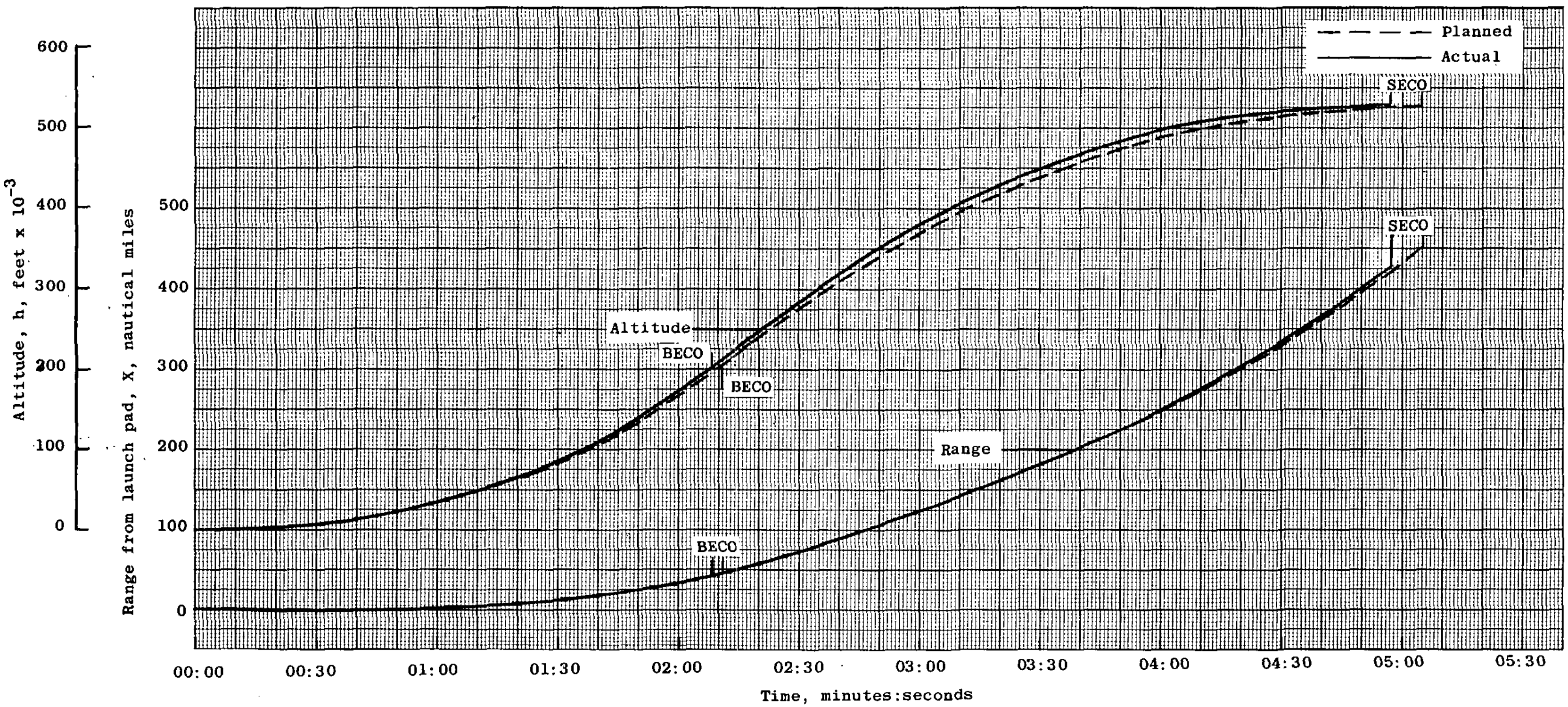


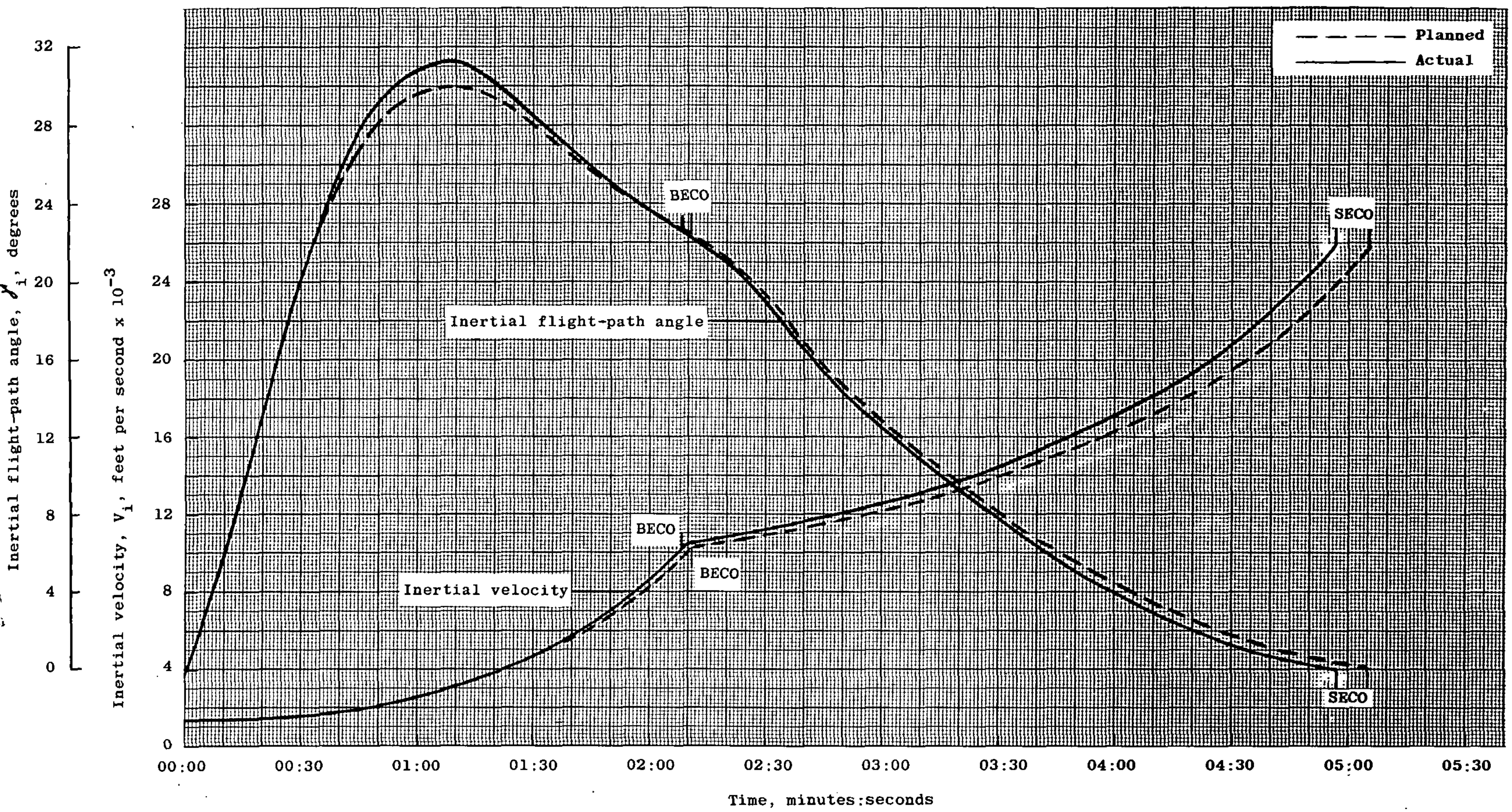
Figure 2. - Altitude versus longitude profile.



(a) Altitude and range versus time.

Figure 3. - Time histories of trajectory parameters for MA-4 mission launch phase.

[redacted]

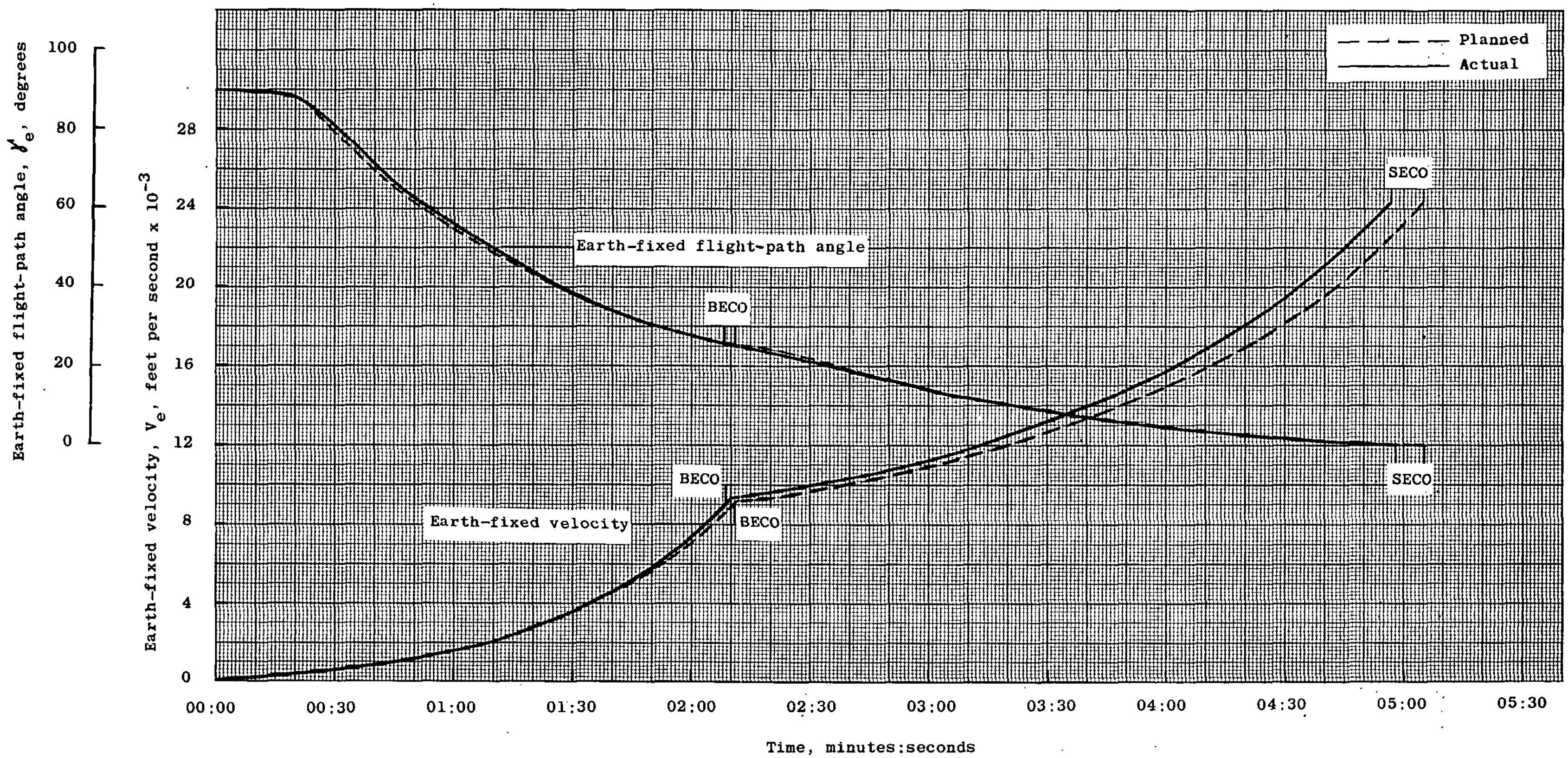


(b) Inertial velocity and flight-path angle versus time.

Figure 3. - Continued.

[redacted]

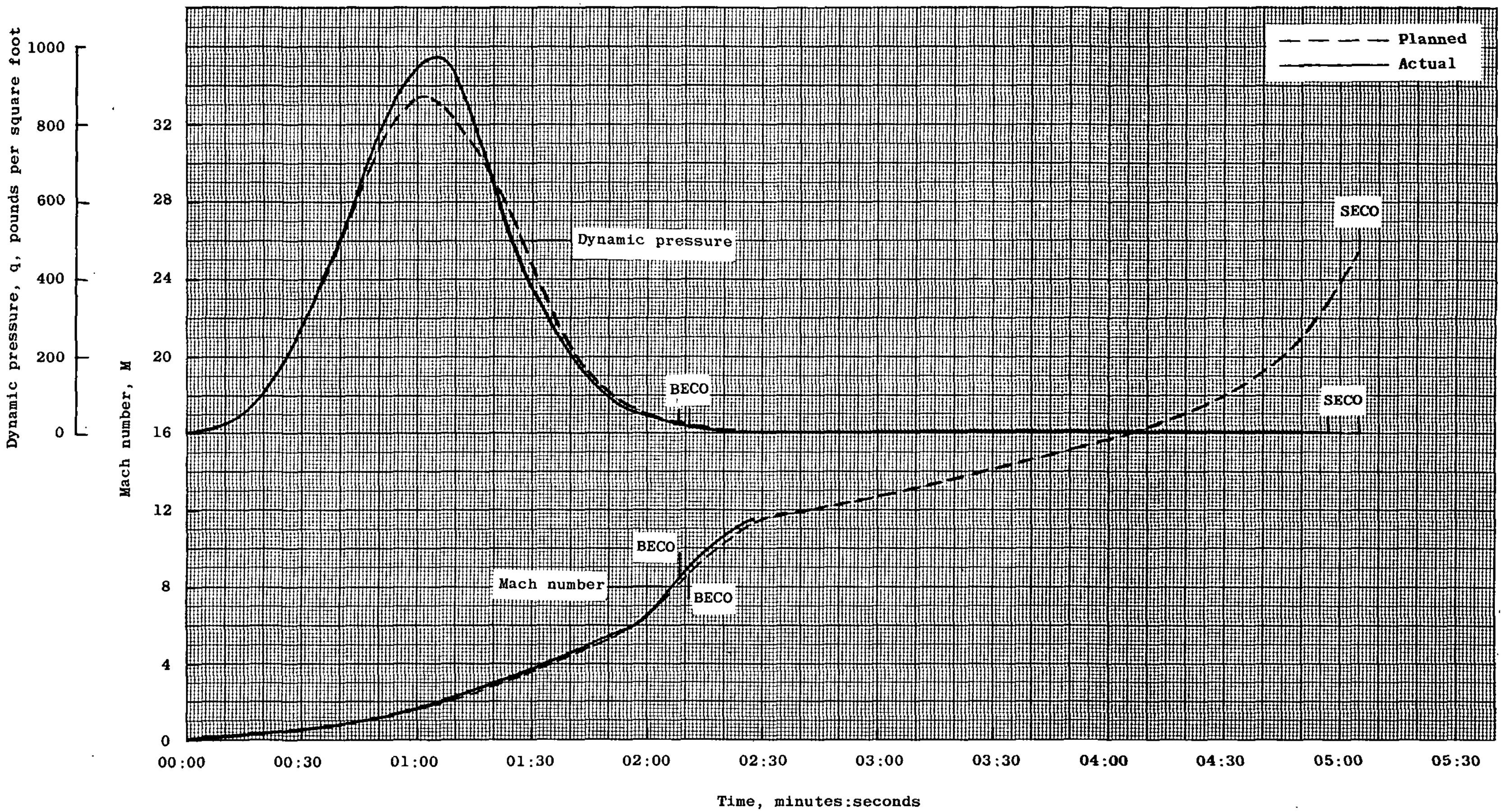
[redacted]



(c) Earth-fixed velocity and flight-path angle versus time.

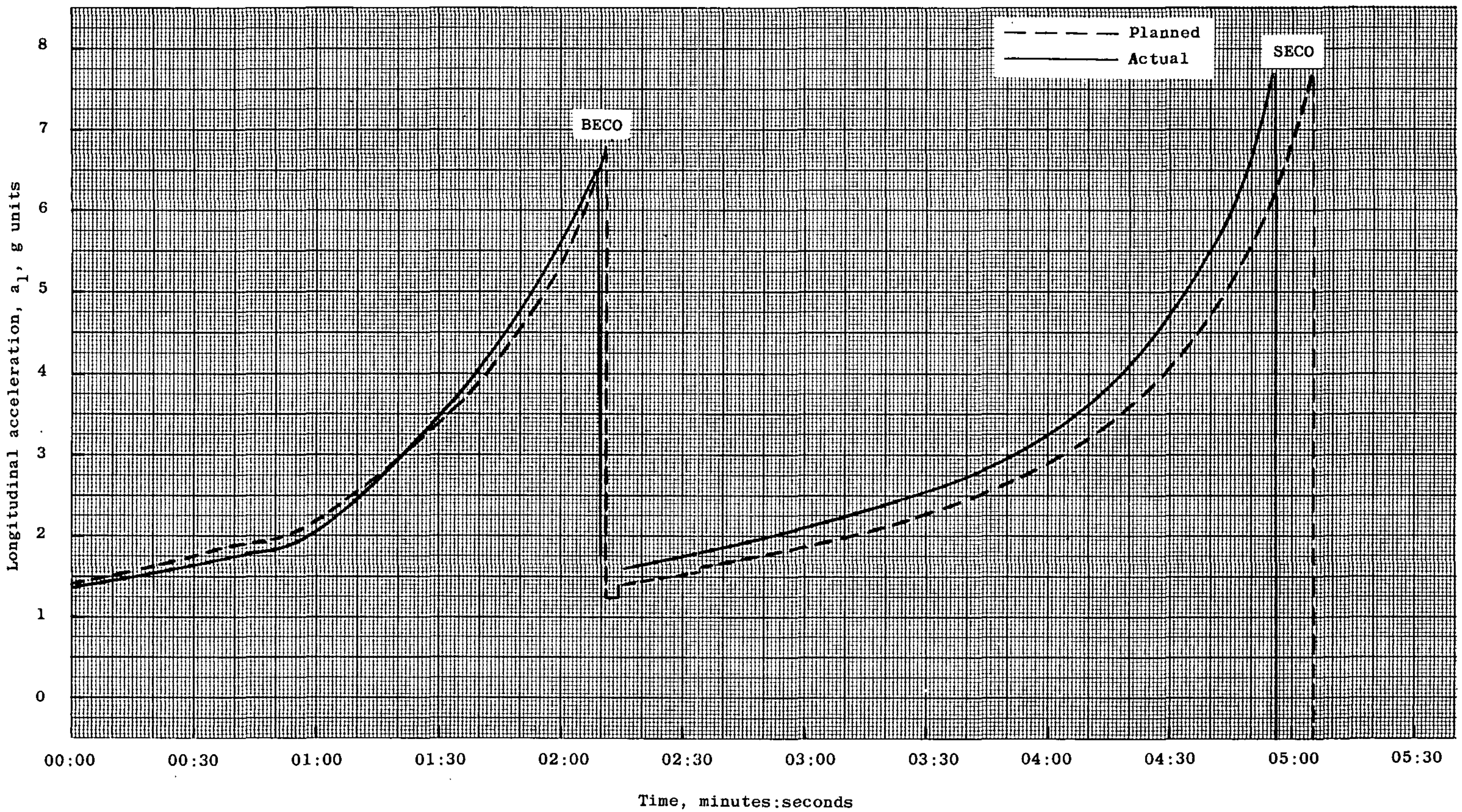
Figure 3.- Continued.

[redacted]



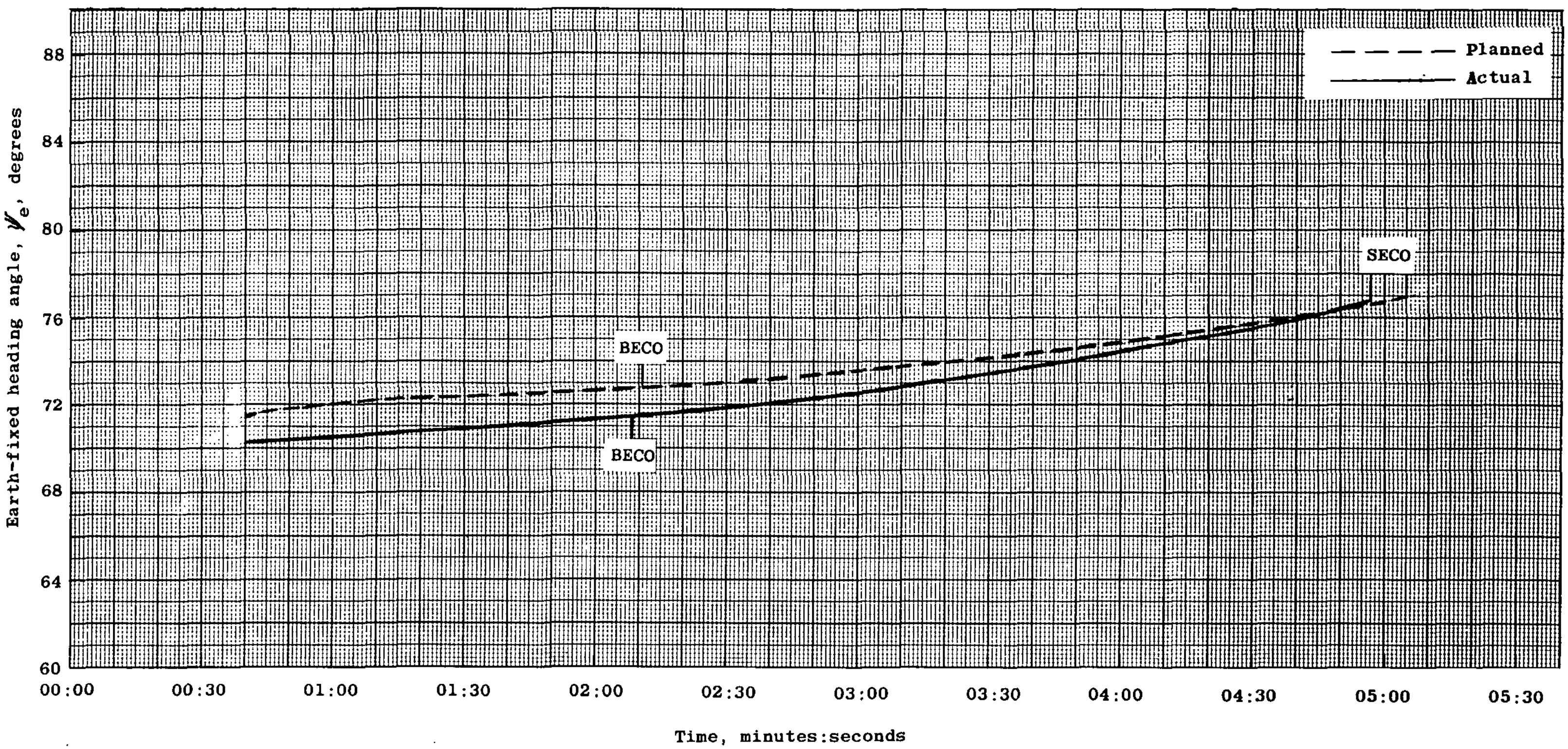
(d) Dynamic pressure and Mach number versus time.

Figure 3.- Continued.



(e) Longitudinal acceleration versus time, along capsule Z-axis

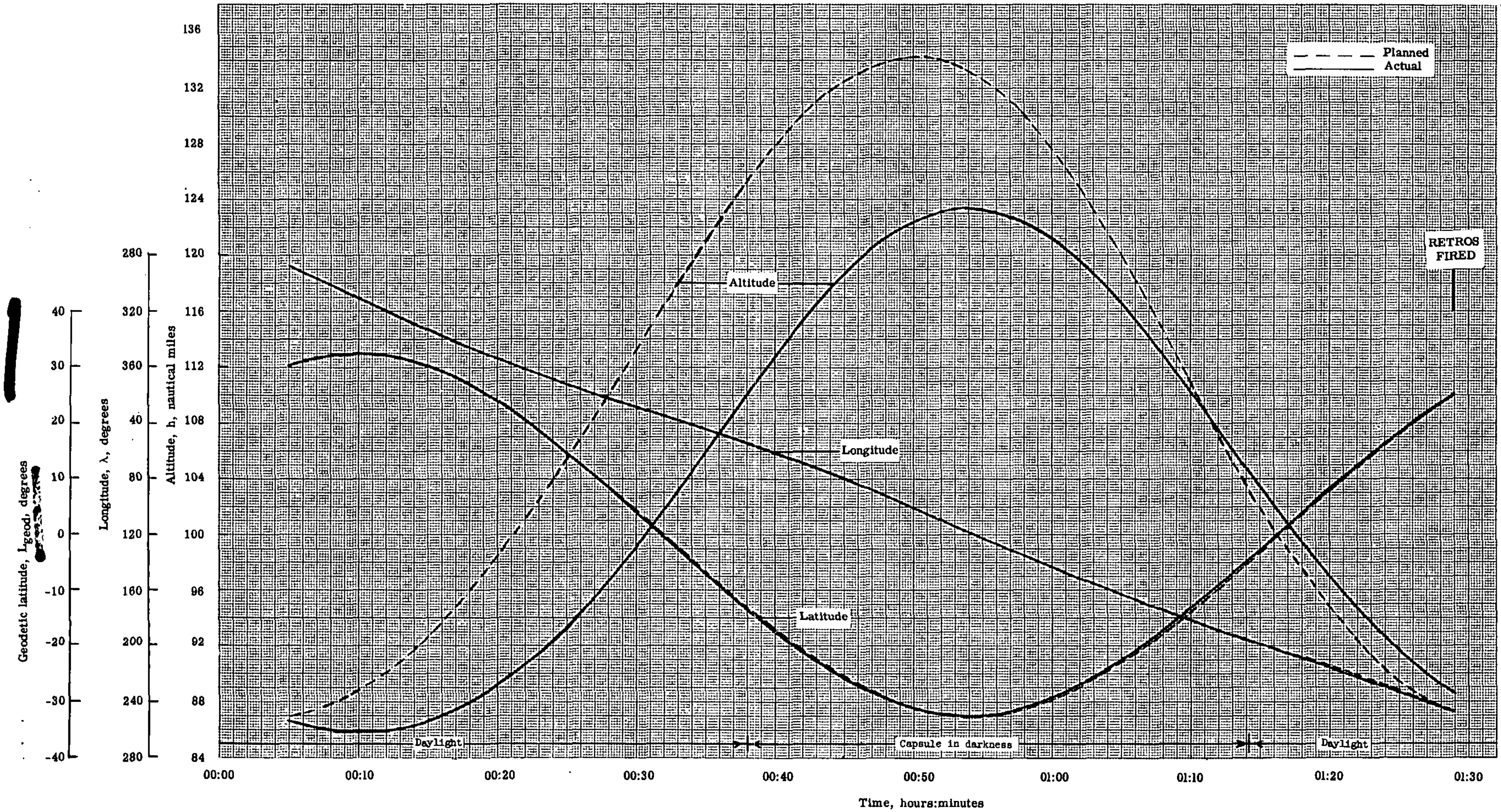
Figure 3. - Continued.



(f) Earth-fixed heading angle versus time.

Figure 3. - Concluded.

[redacted]

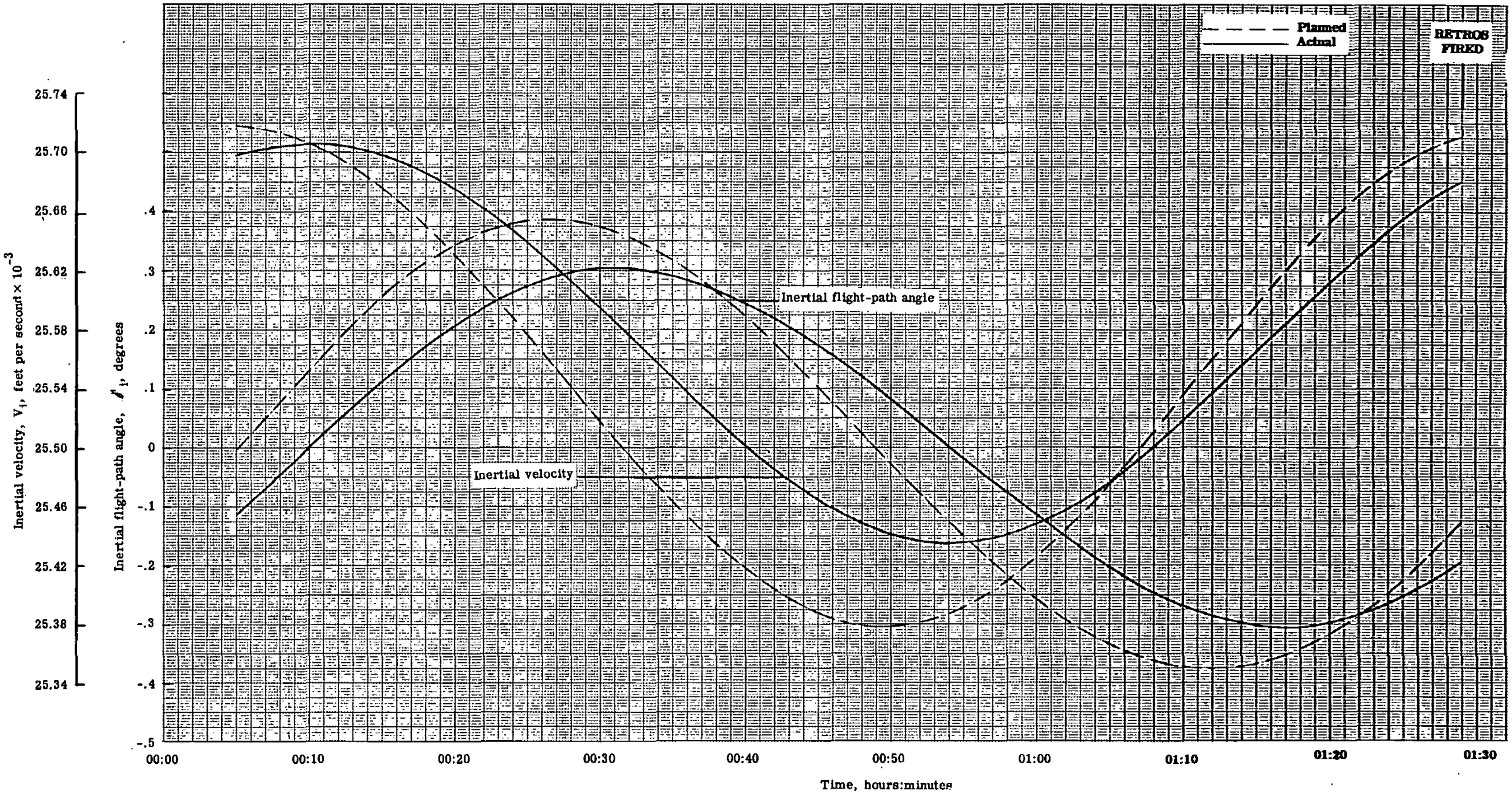


(a) Latitude, longitude, and altitude versus time.

Figure 4. - Time histories of trajectory parameters for MA-4 mission orbit phase.

[redacted]

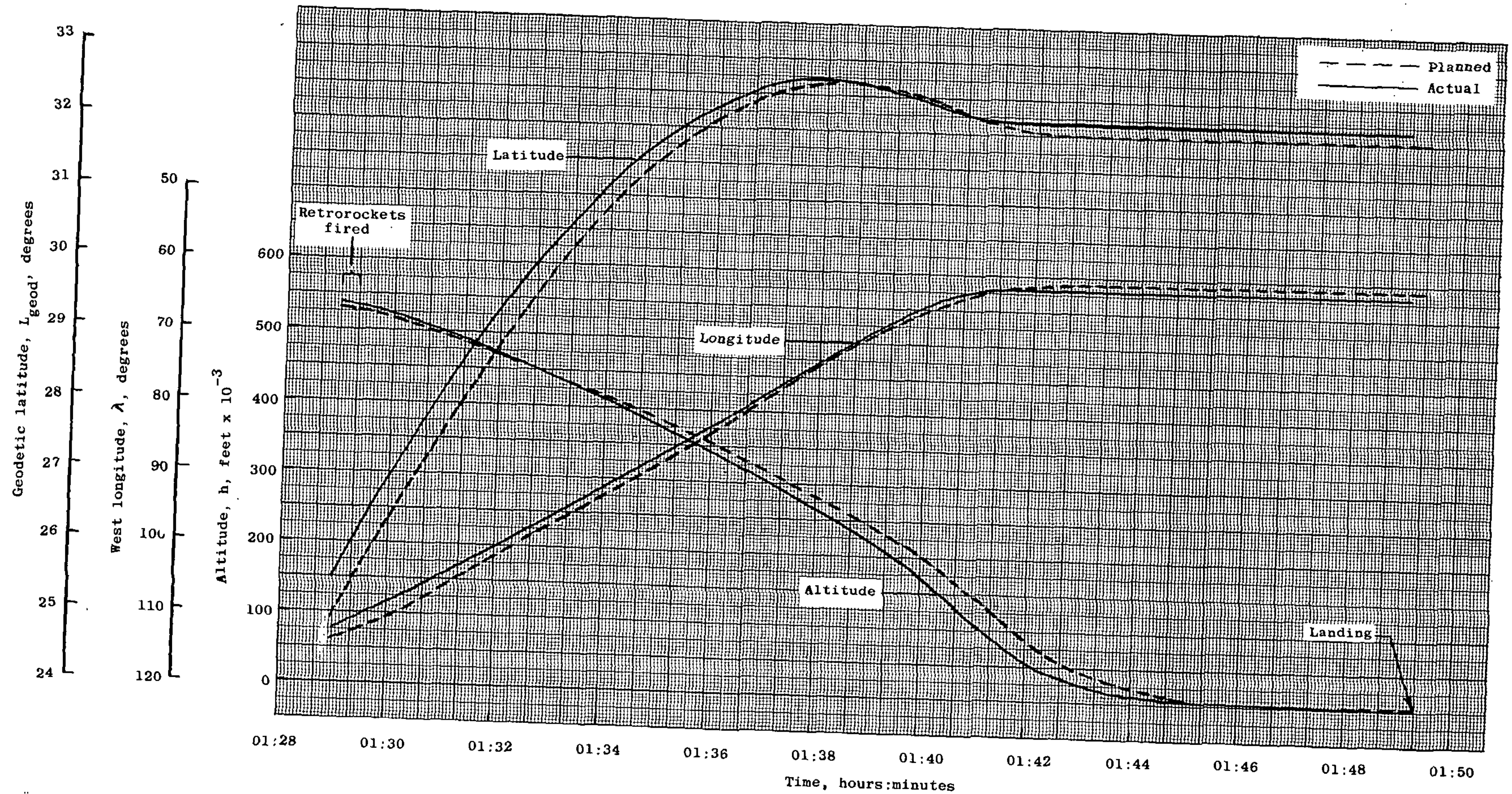
Page 8 - 9



(b) Inertial velocity and flight-path angle versus time.

Figure 4. - Concluded.

[redacted]

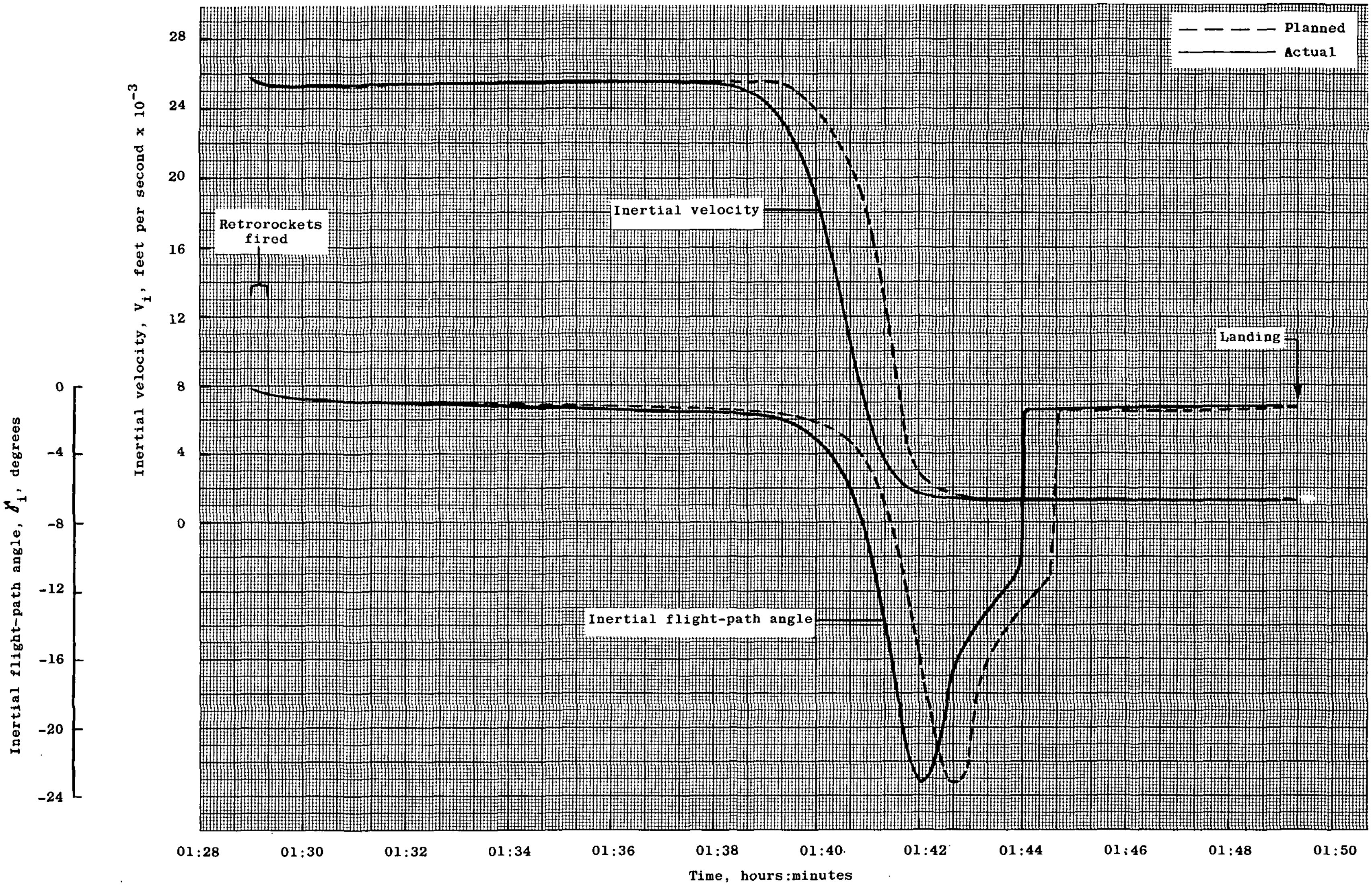


(a) Latitude, longitude, and altitude versus time.

Figure 5. - Time histories of trajectory parameters for MA-4 mission reentry phase.

[redacted]

[redacted]

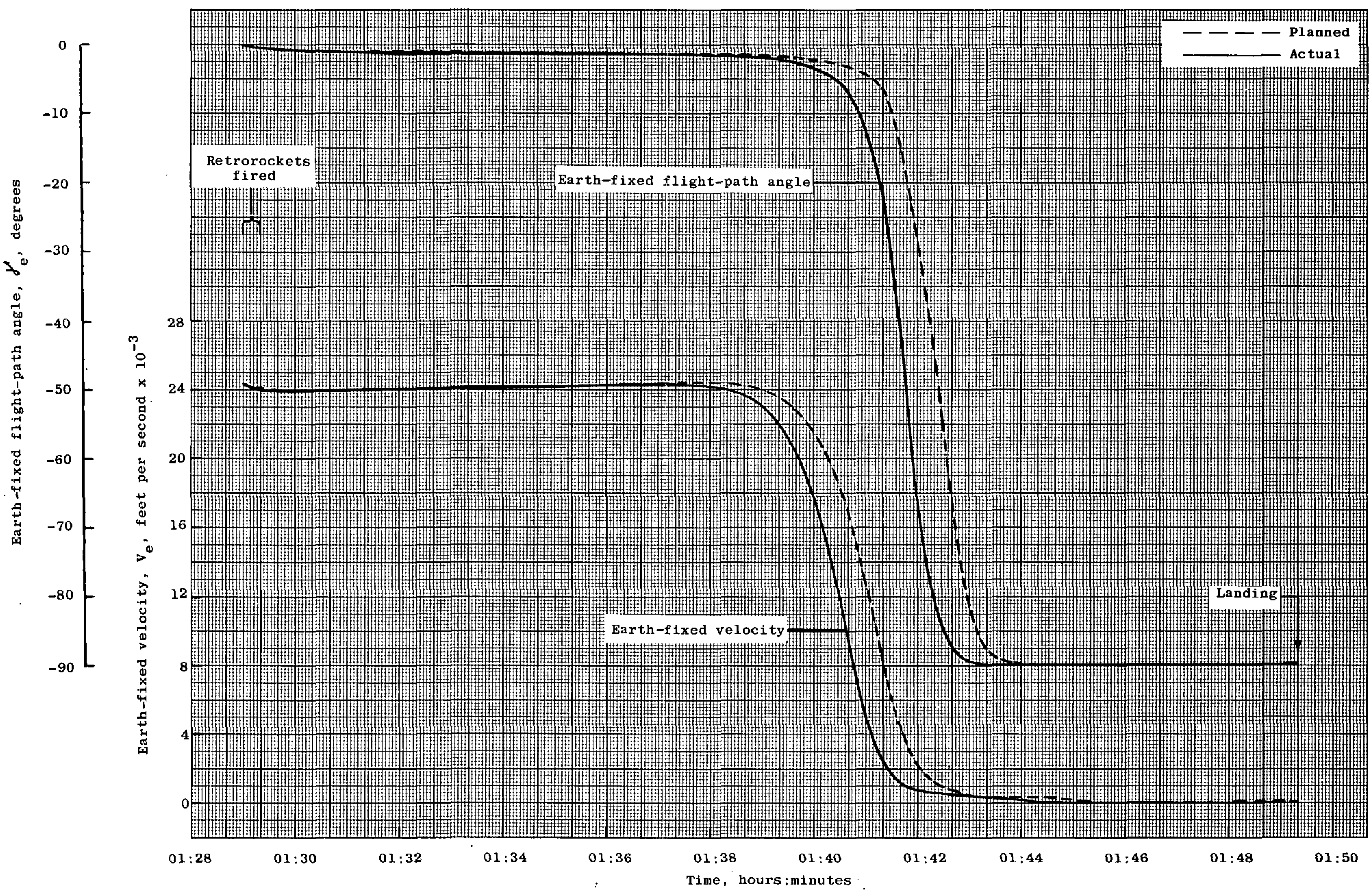


(b) Inertial velocity and flight-path angle versus time.

Figure 5. - Continued.

[redacted]

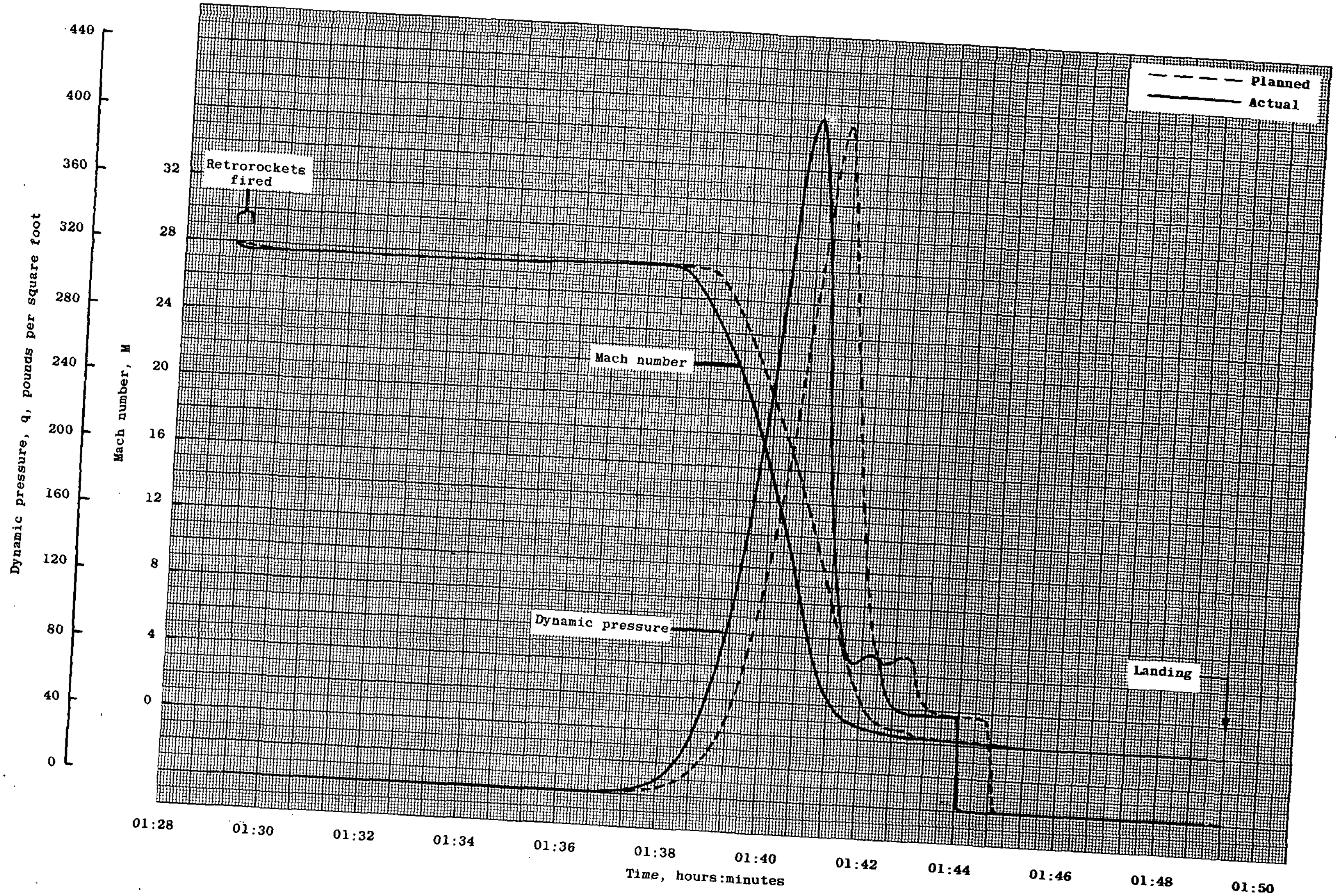
[redacted]



(c) Earth-fixed velocity and flight-path angle versus time.

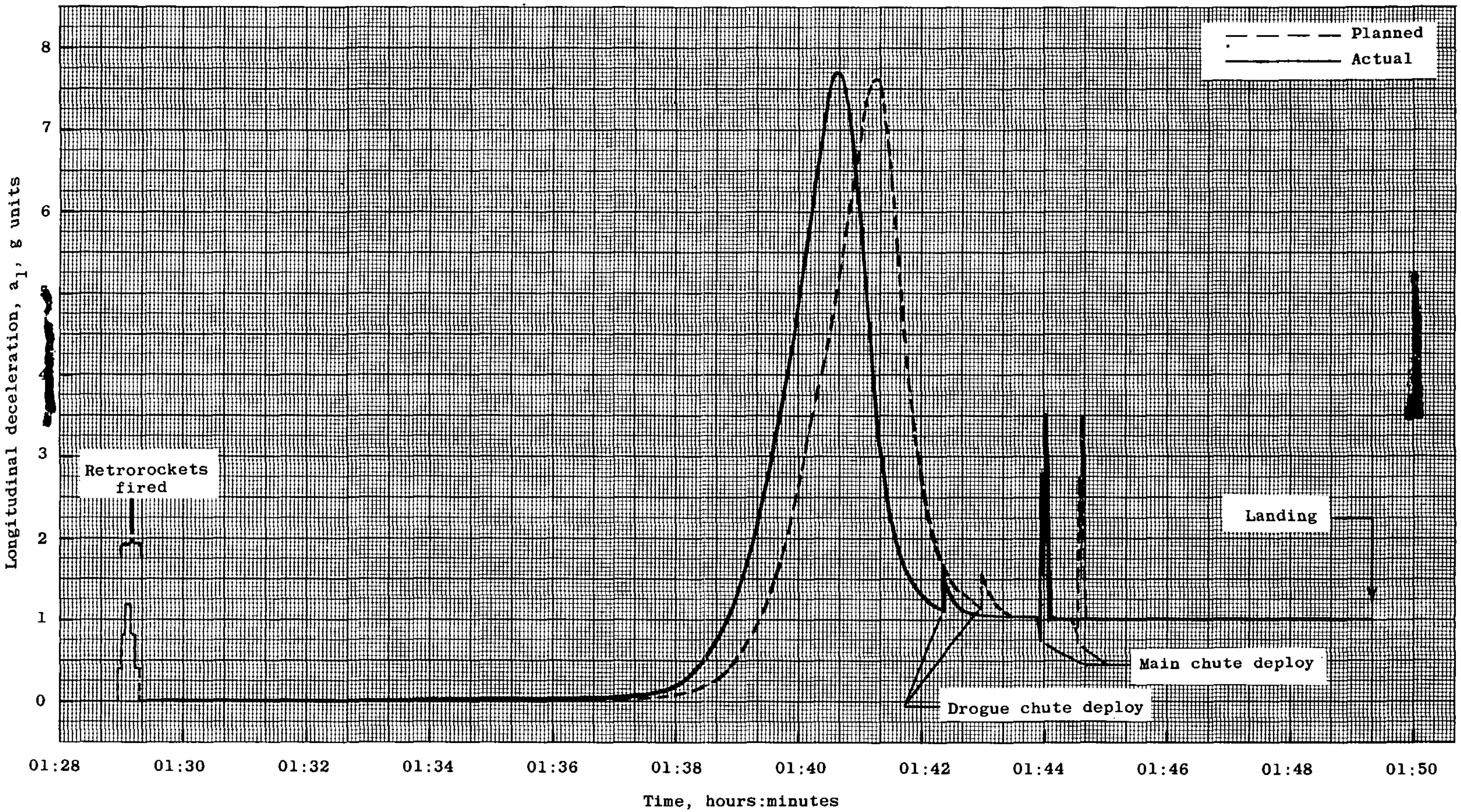
Figure 5. - Continued.

[redacted]



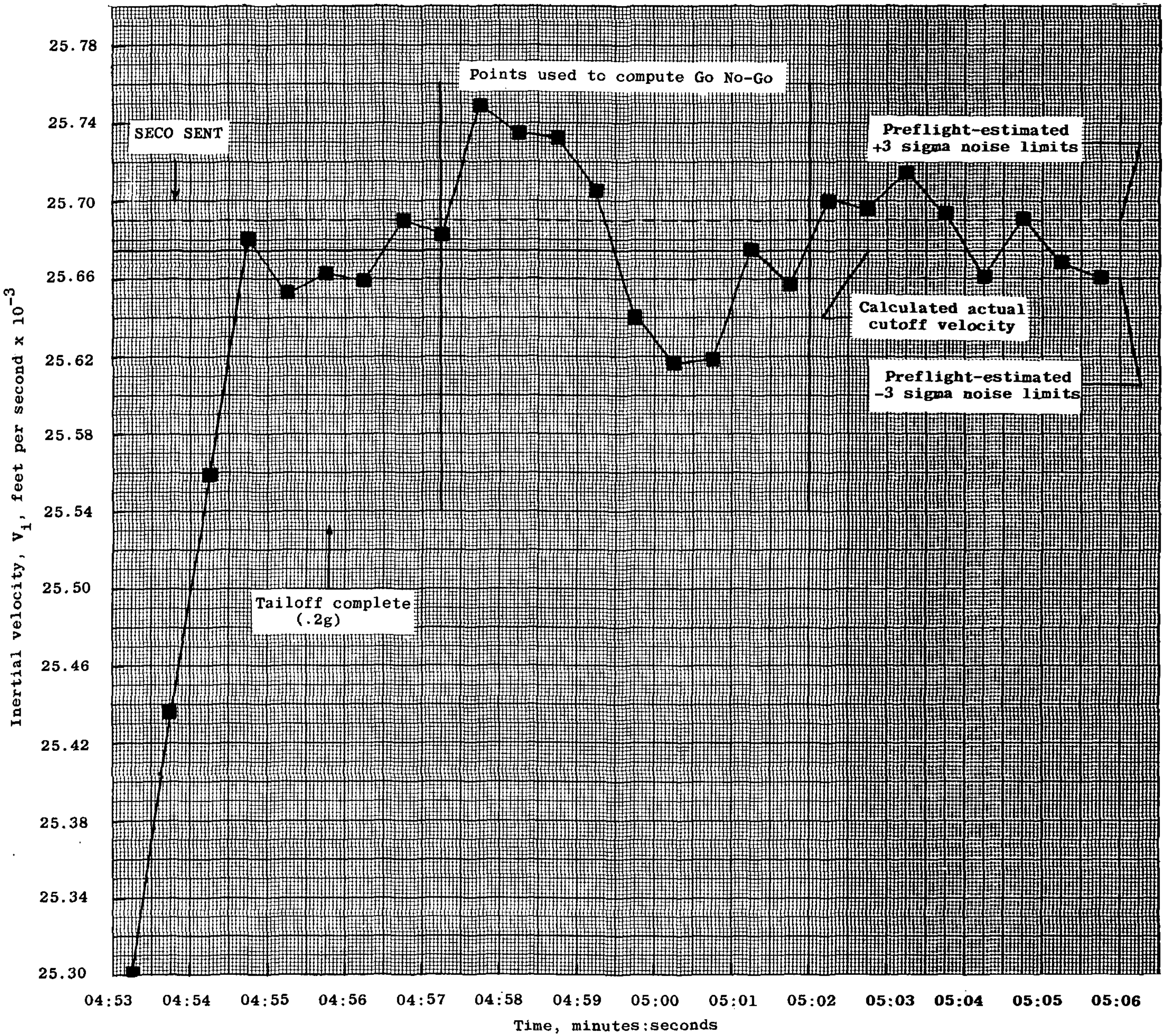
(d) Dynamic pressure and Mach number versus time.

Figure 5. - Continued.



(e) Longitudinal deceleration versus time, along capsule Z-axis.

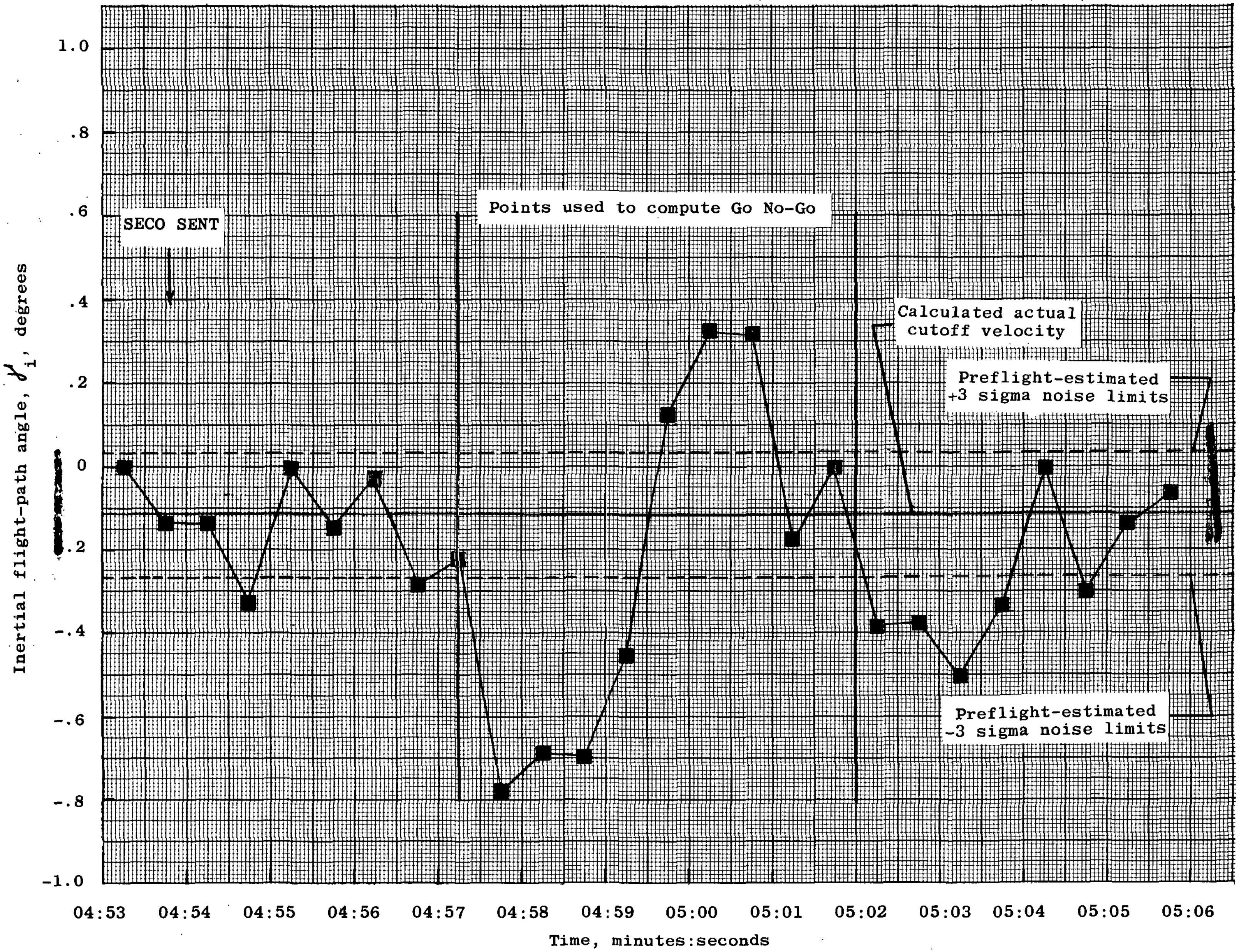
Figure 5. - Concluded.



(a) Inertial velocity.

Figure 6. - Inertial velocity and flight-path angle in the region of cutoff using G.E.-Burroughs data.

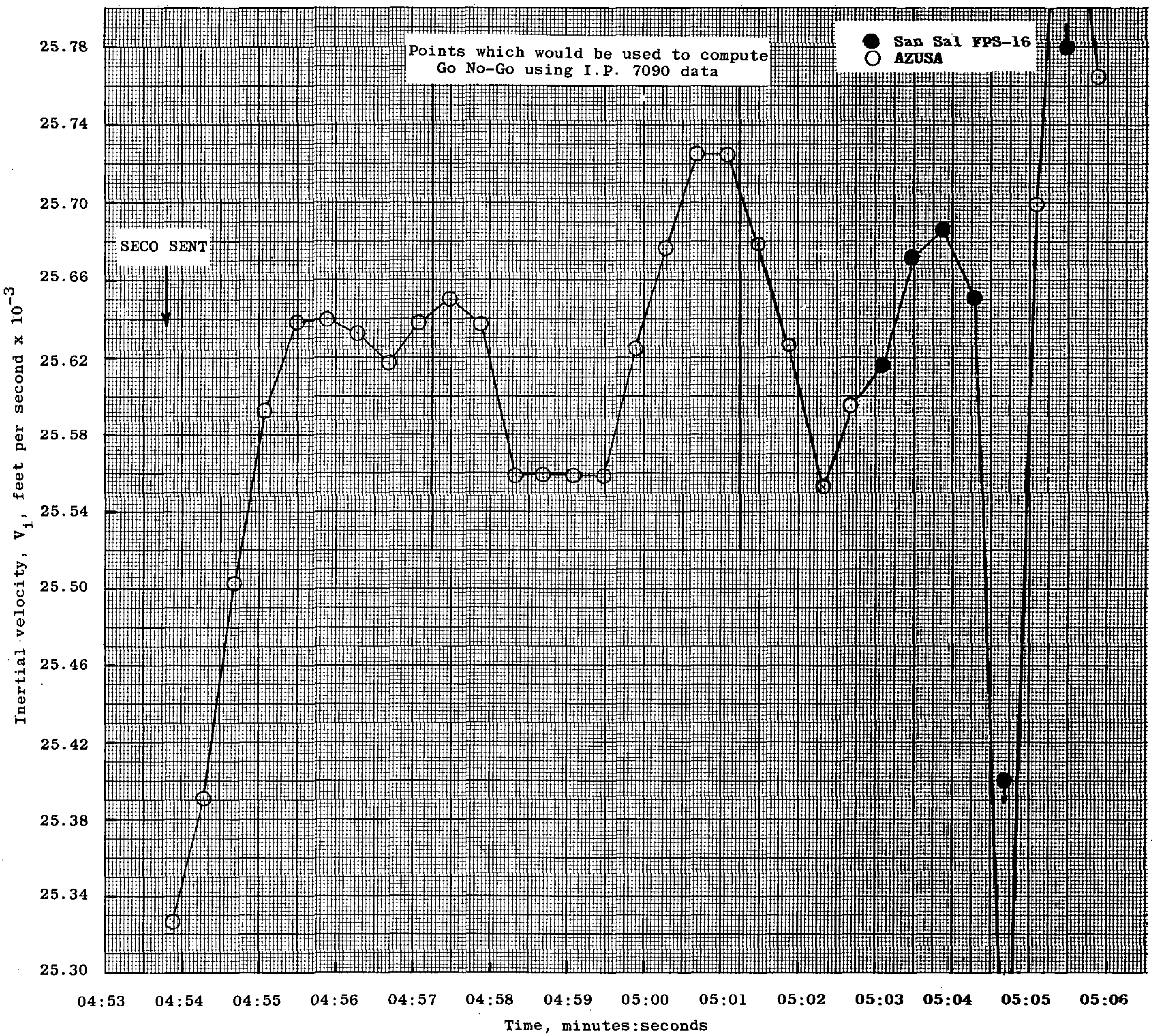
[redacted]



(b) Inertial flight-path angle.

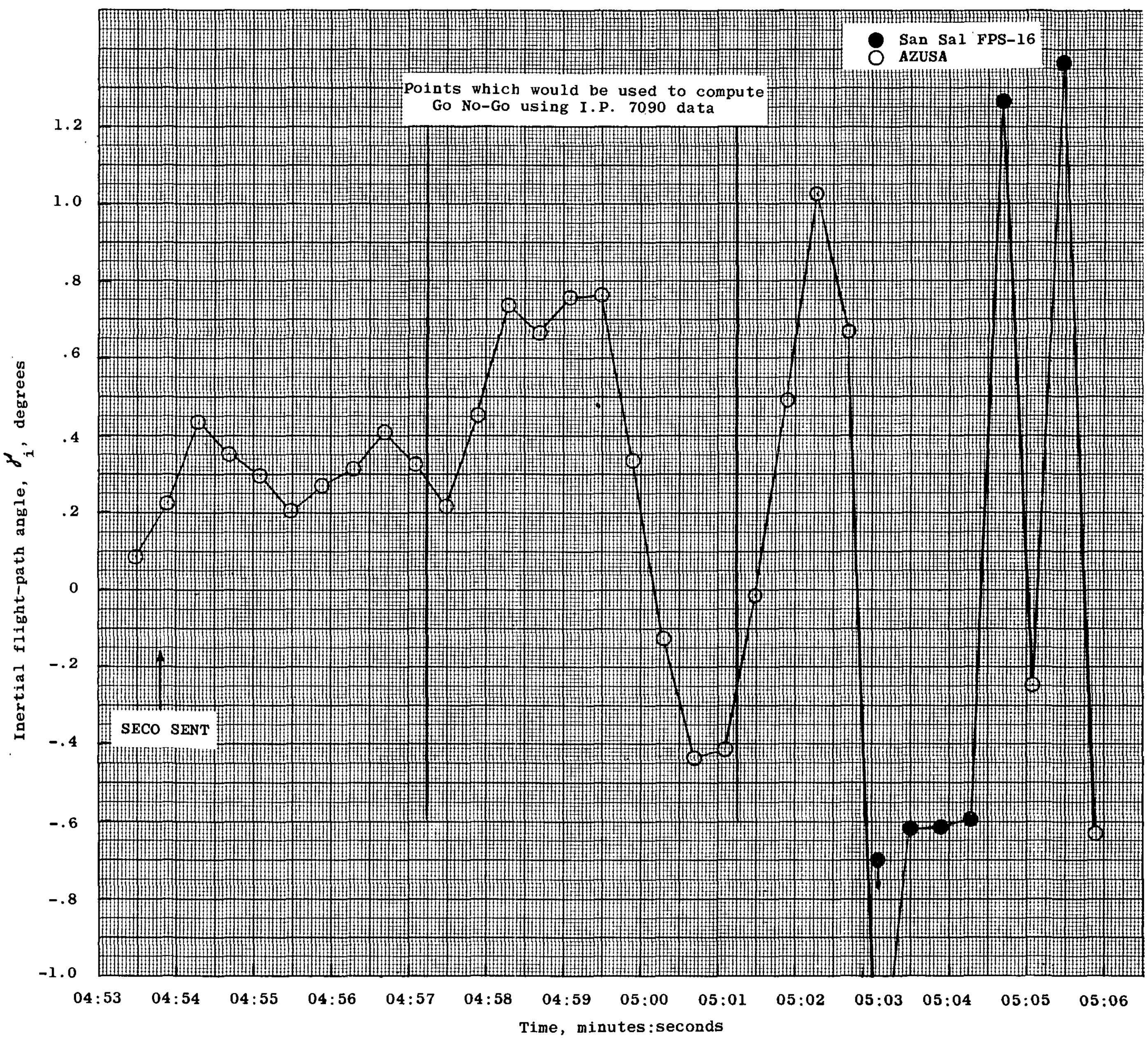
Figure 6. - Concluded.

[redacted]



(a) Inertial velocity.

Figure 7. - Inertial velocity and flight-path angle in the region of cutoff using I.P. 7090 data.



(b) Inertial flight-path angle.

Figure 7. - Concluded.

[redacted]

[redacted]

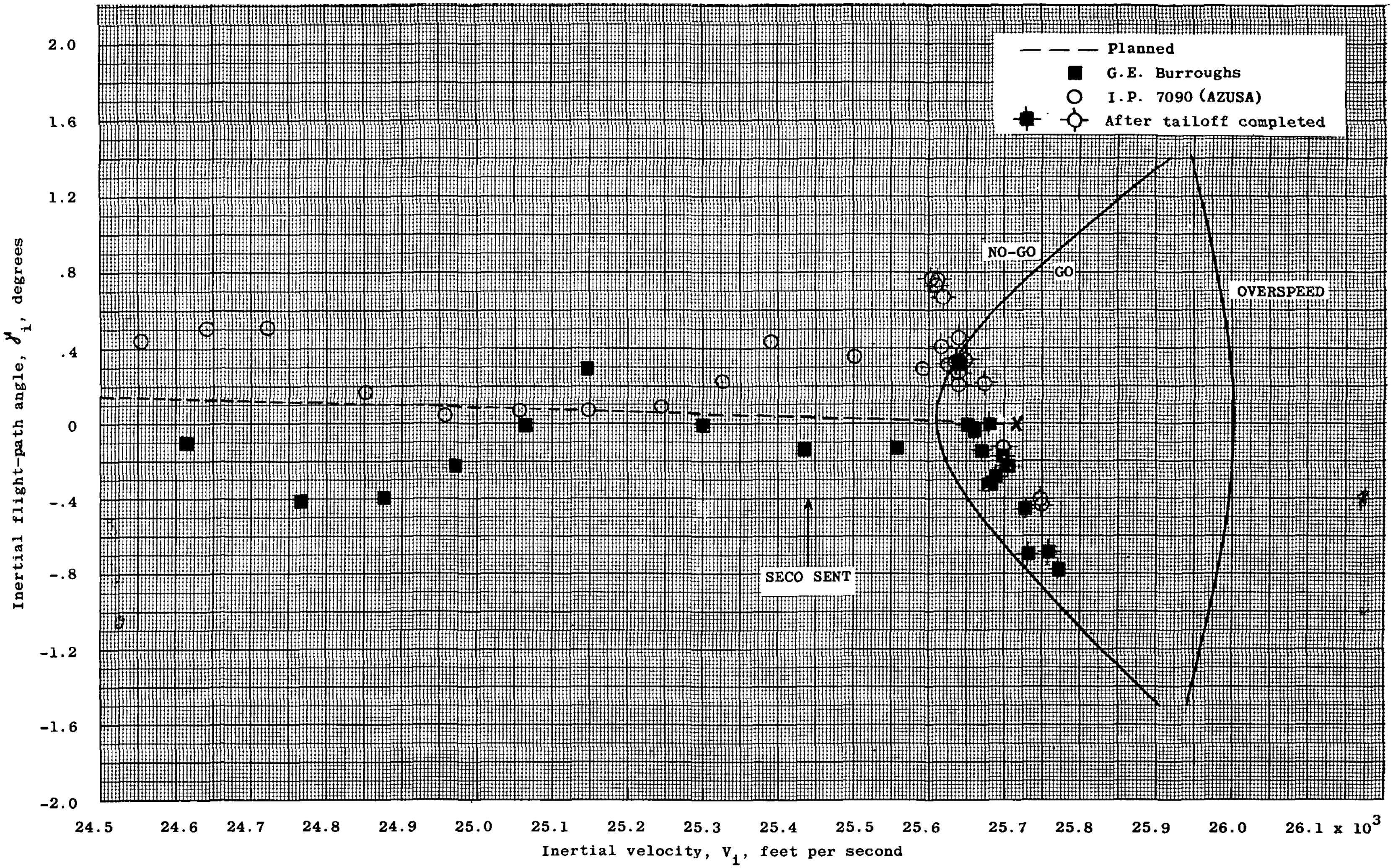


Figure 8. - Inertial flight-path angle versus inertial velocity in the region of cutoff.

[redacted]

[redacted]

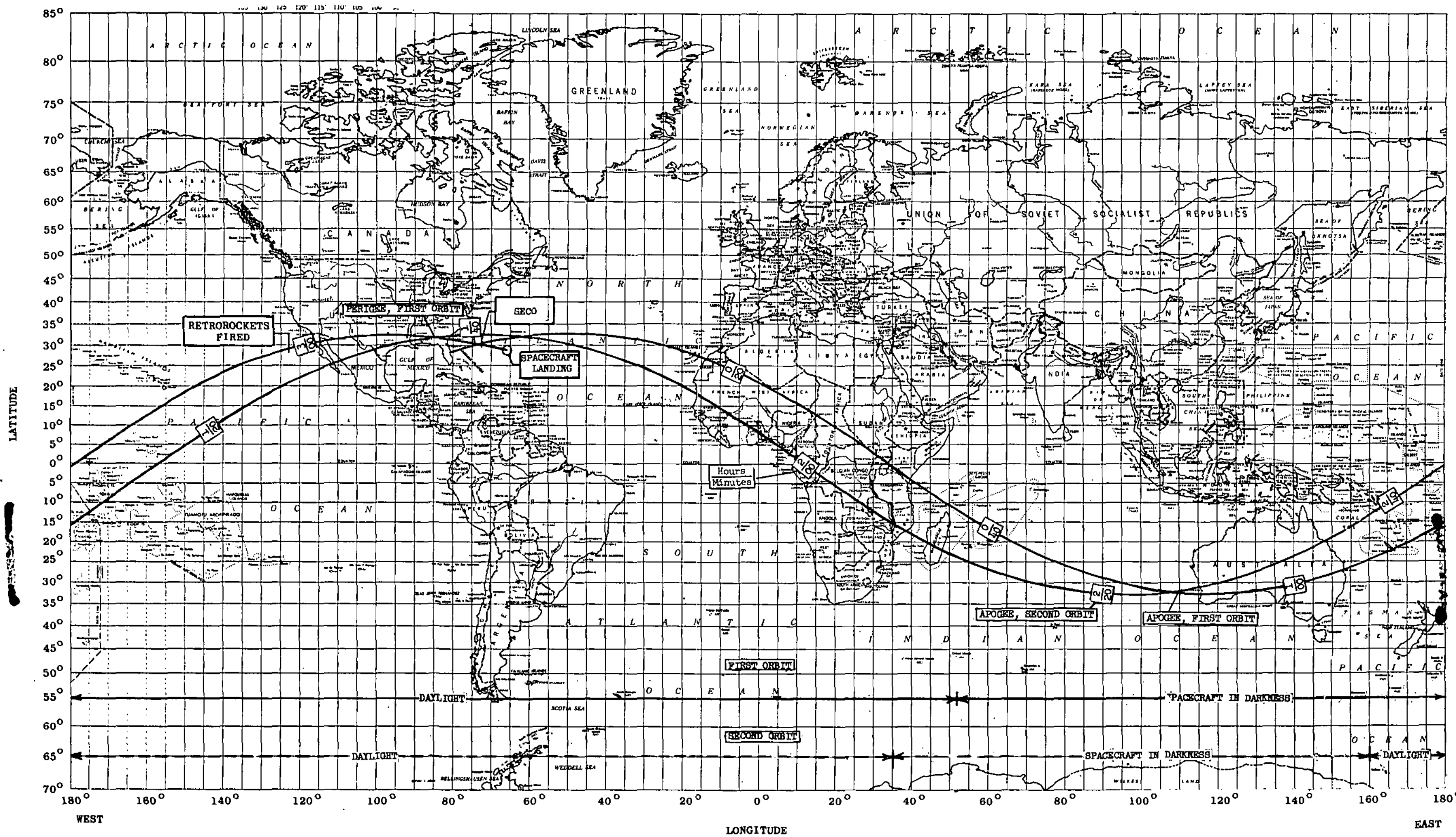


Figure 9 .- Ground track for the MA-5 orbital mission.

[redacted]

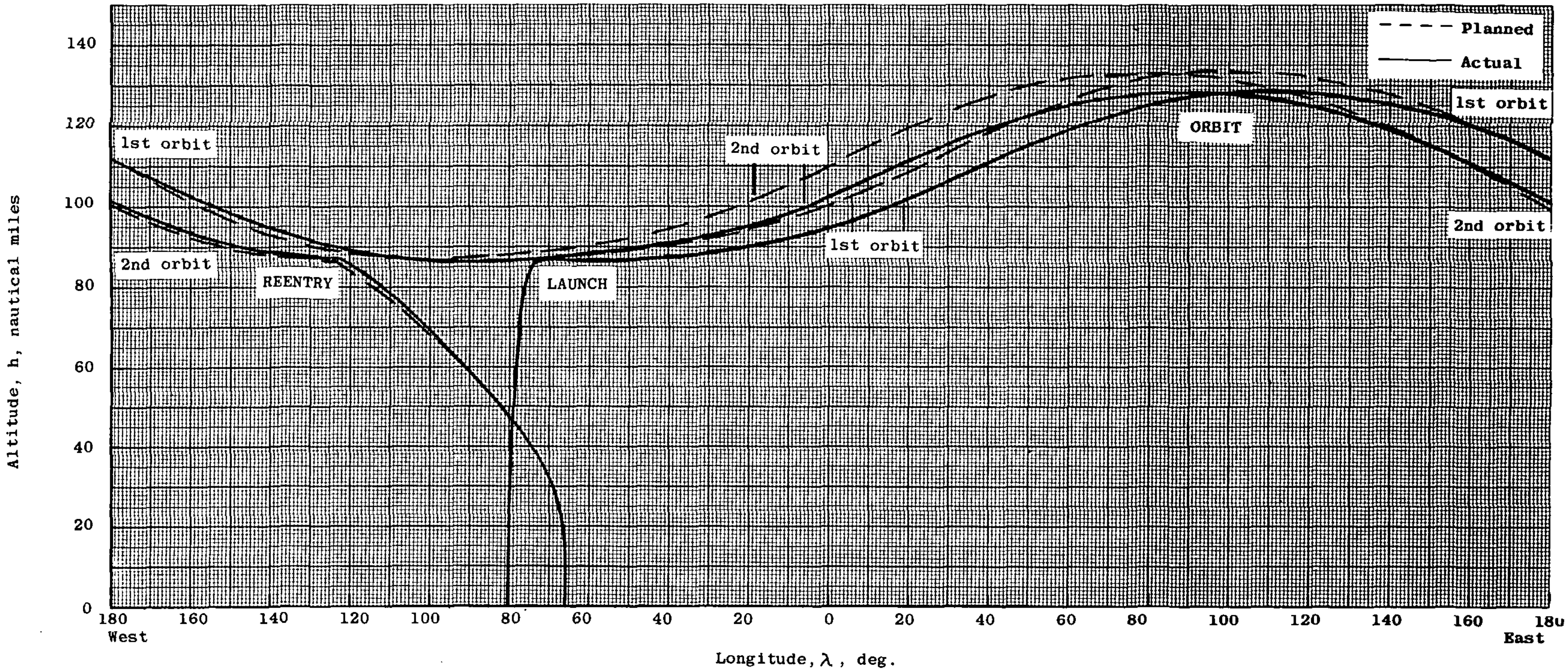
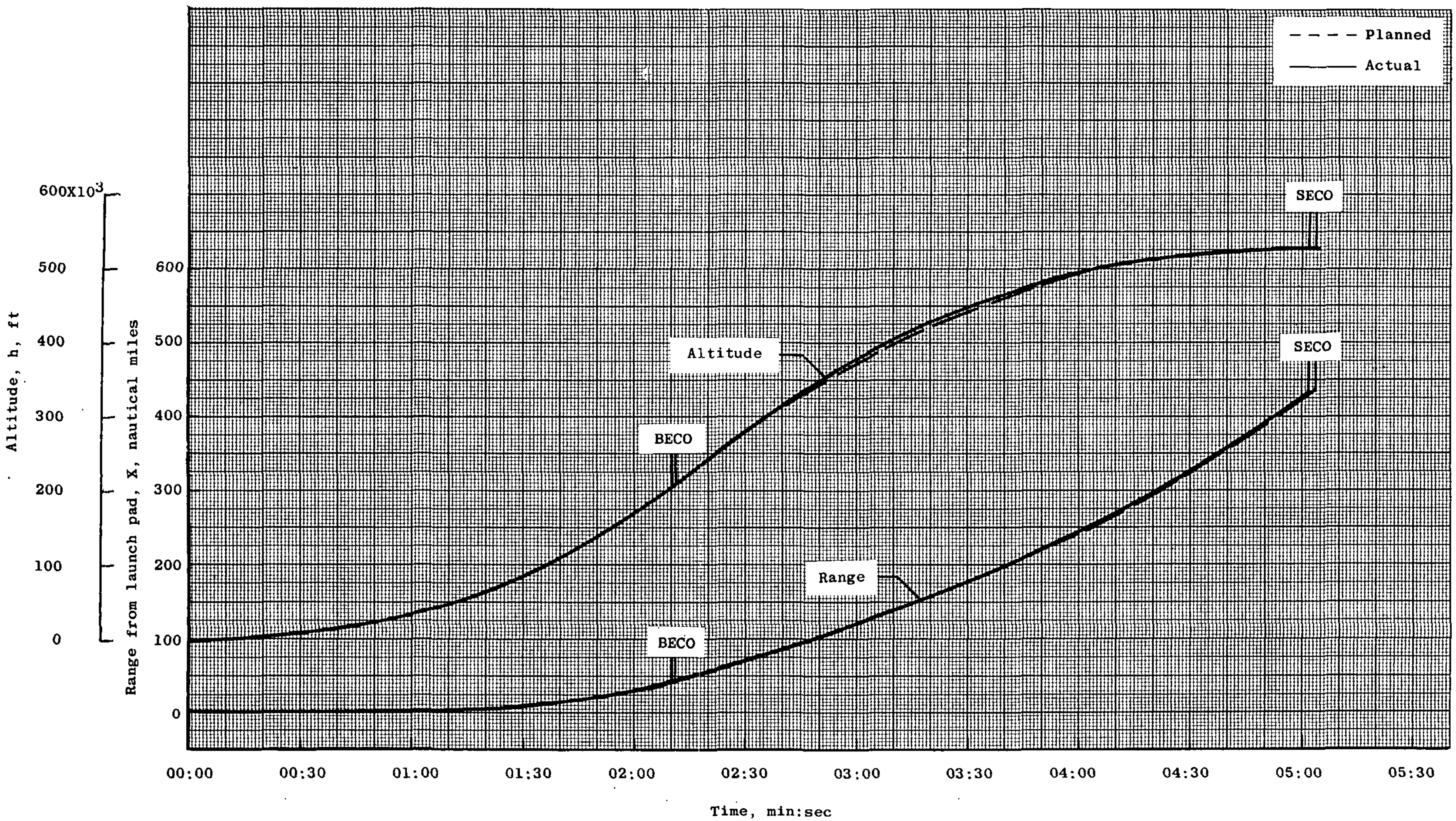
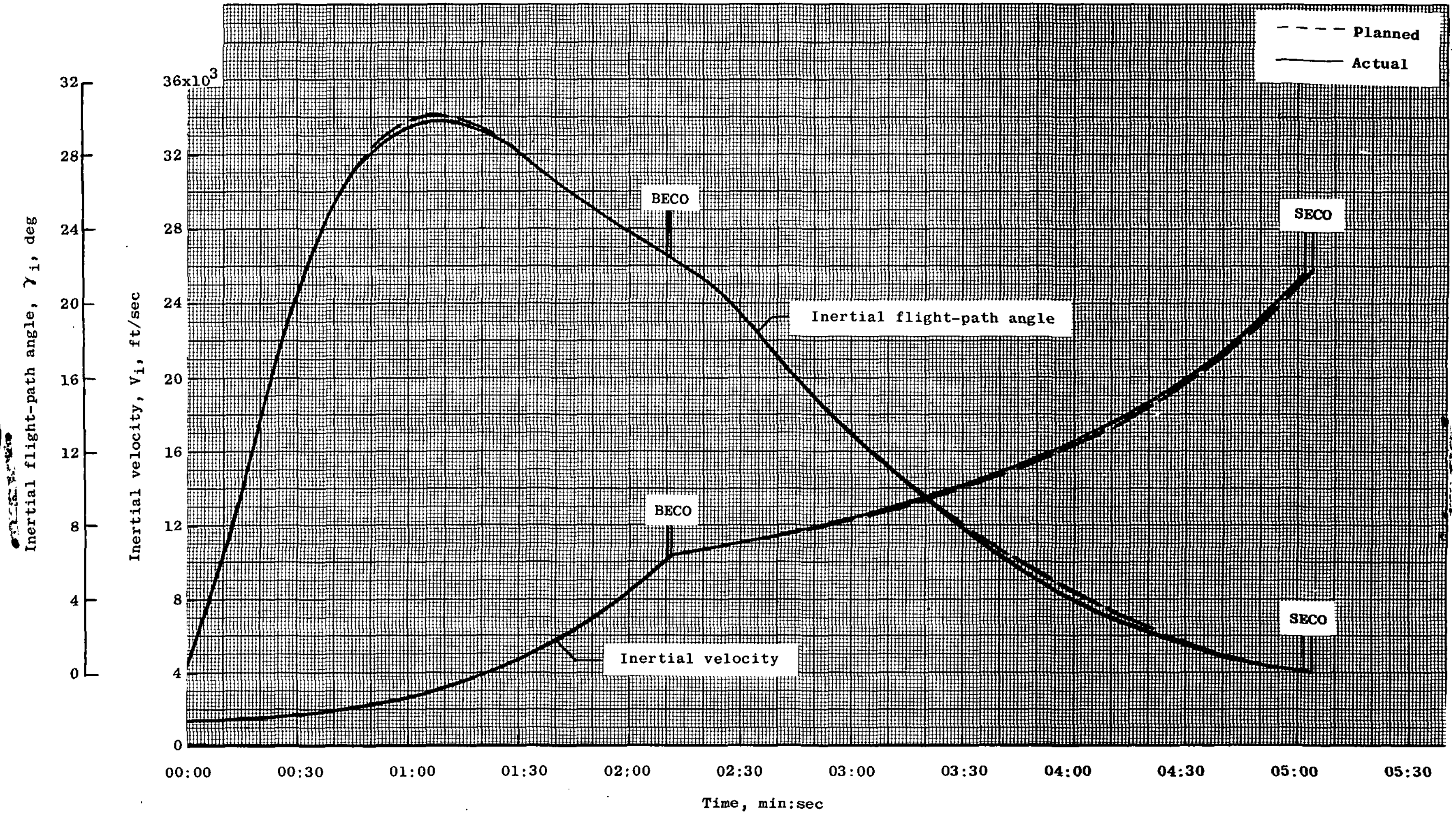


Figure 10. - Altitude versus longitude profile.



(a) Altitude and range versus time.

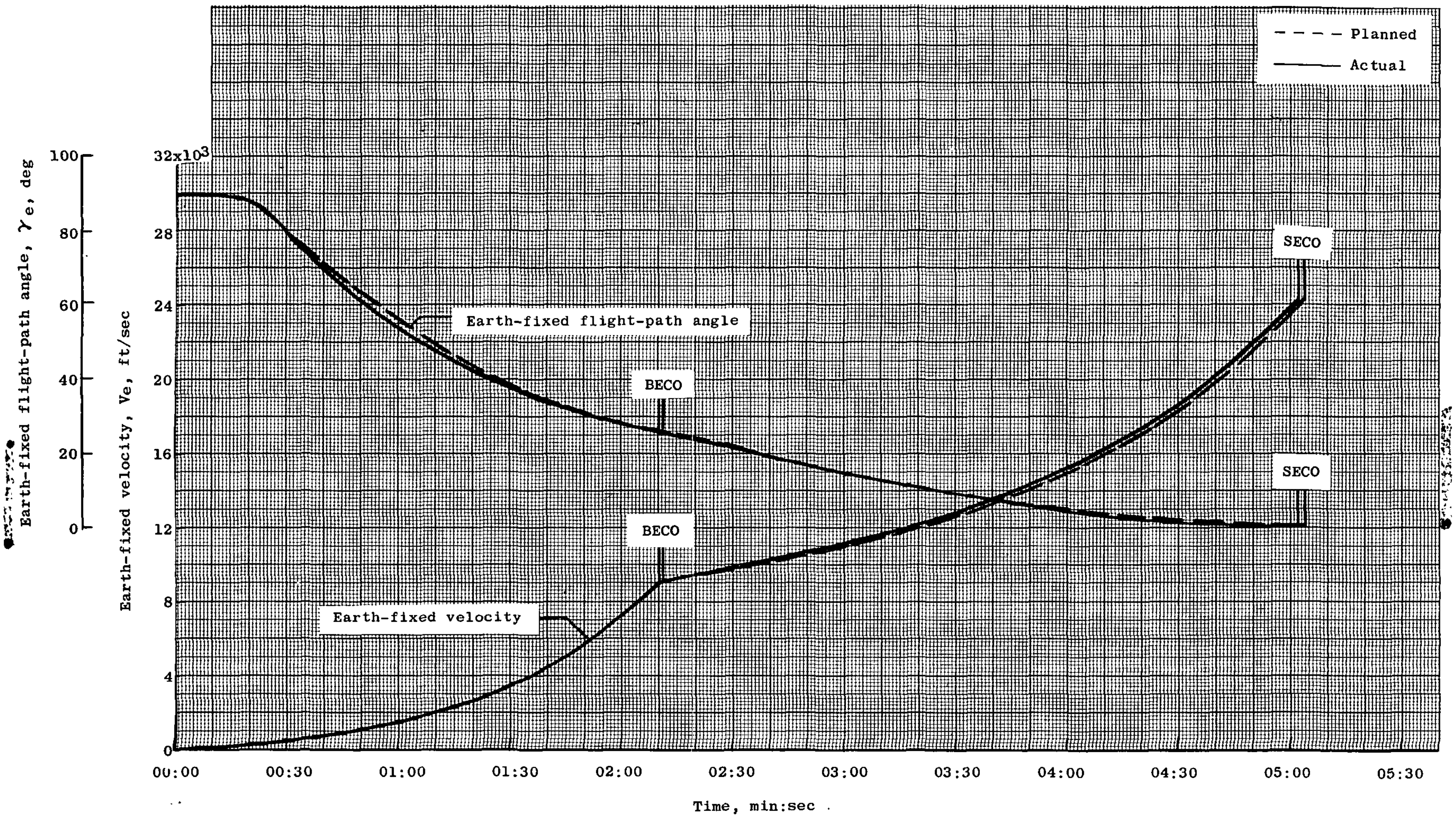
Figure 11 . - Time histories of trajectory parameters for MA-5 mission launch phase.



(b) Inertial velocity and flight-path angle versus time.

Figure 11. - Continued.

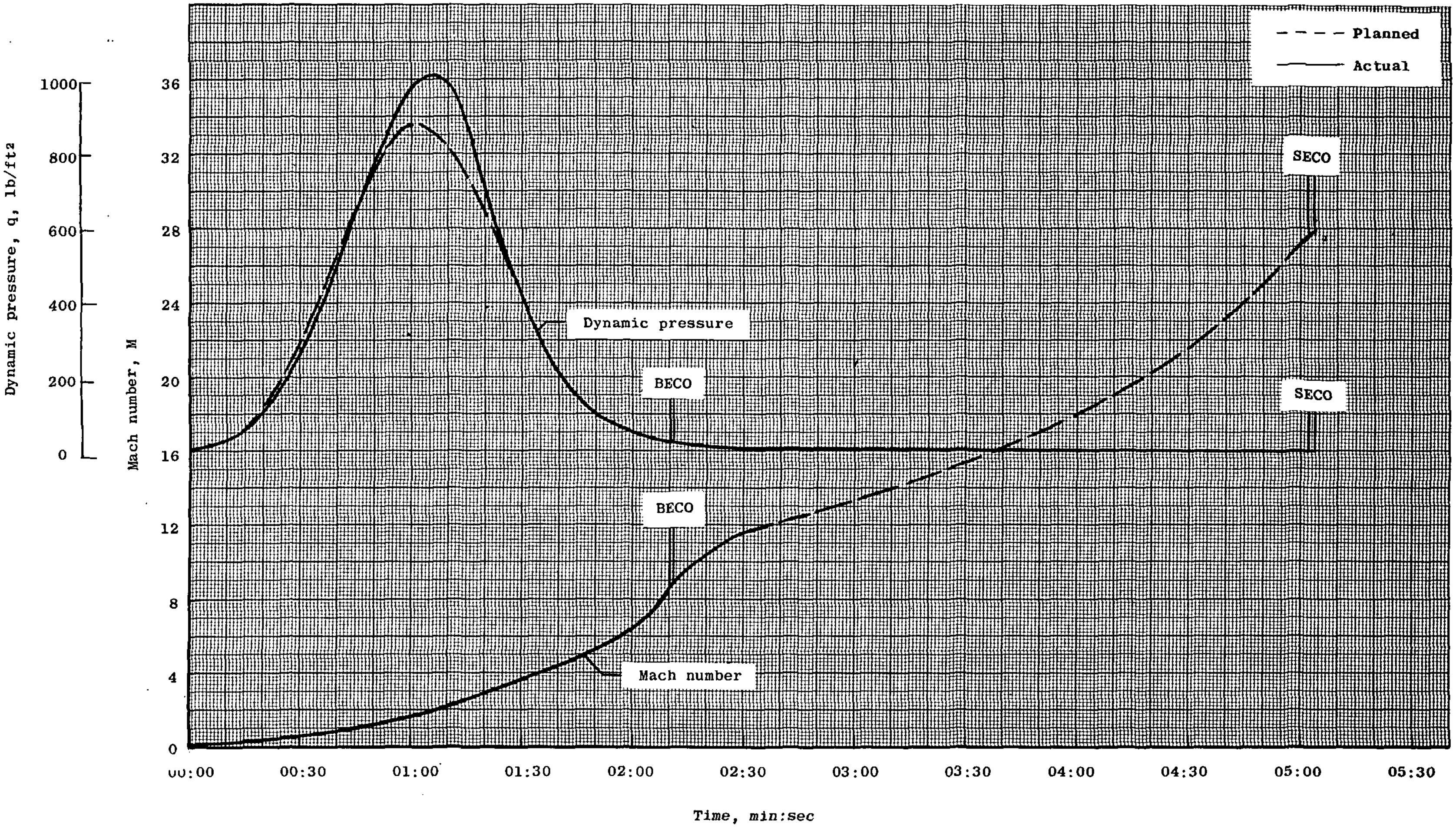
[redacted]



(c) Earth-fixed velocity and flight-path angle versus time.

Figure 11. - Continued.

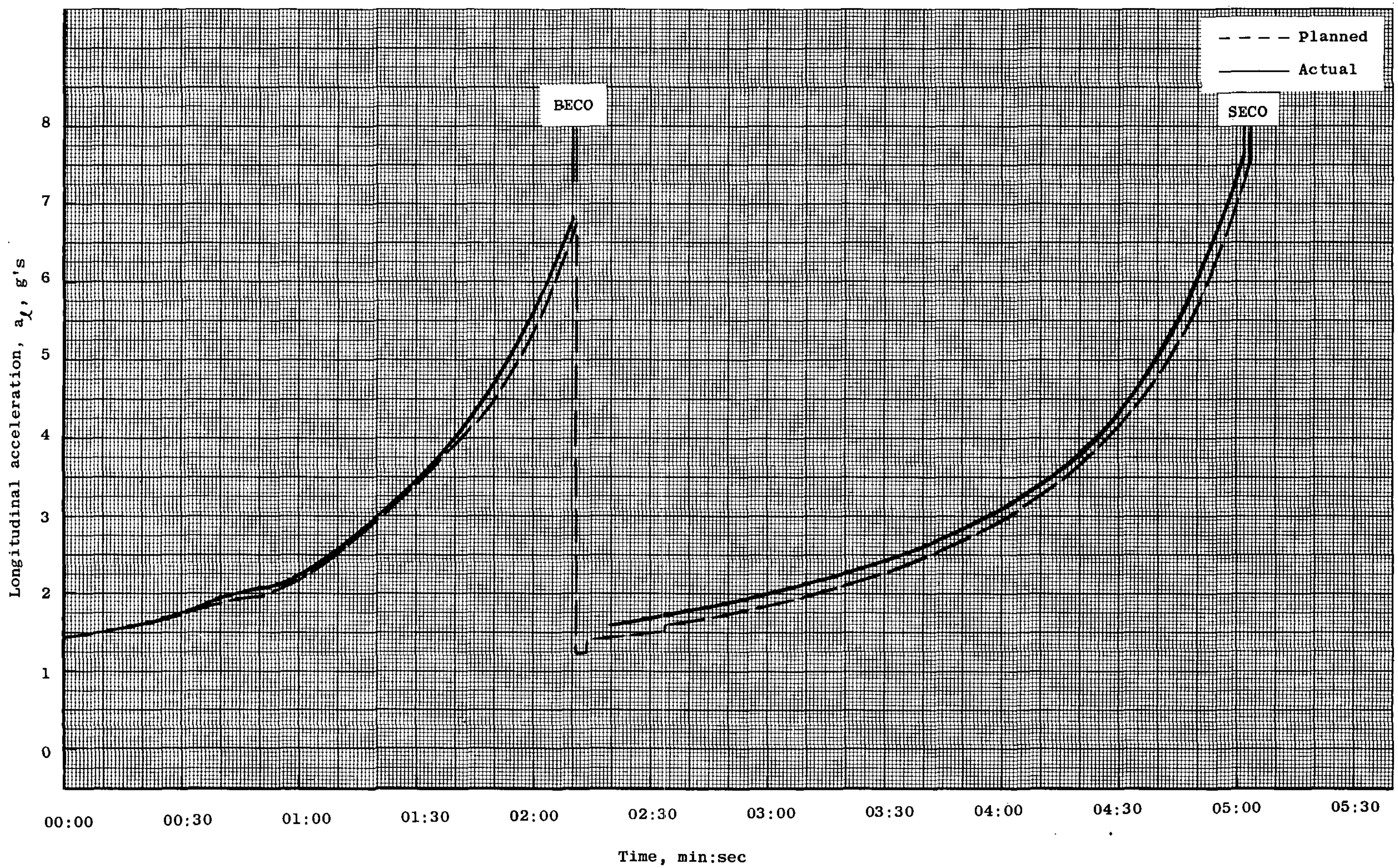
[redacted]



(d) Dynamic pressure and Mach number versus time.

Figure 11 . - Continued.

[redacted]

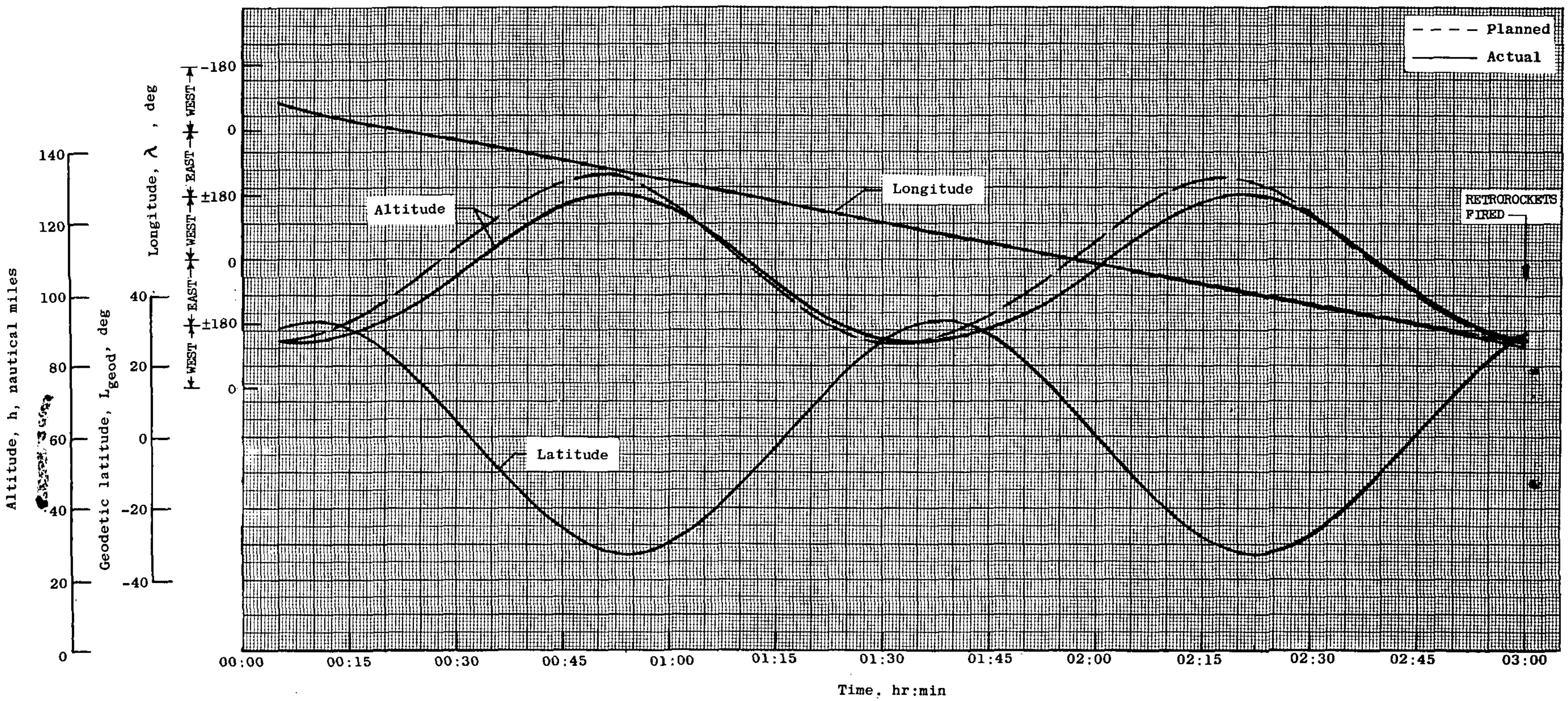


(e) Longitudinal acceleration versus time, along spacecraft Z-axis

Figure 11 .- Concluded.

[redacted]

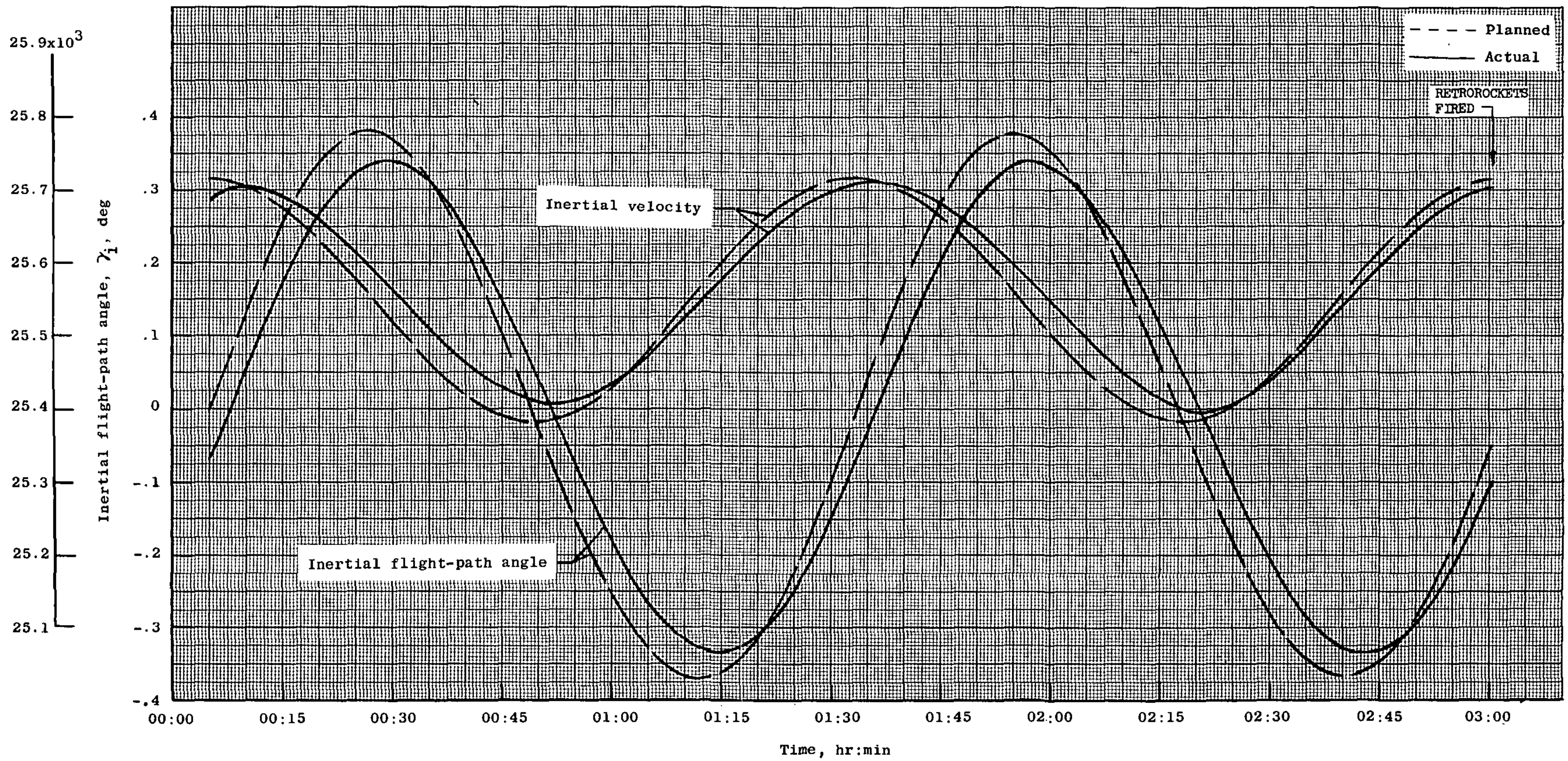
[redacted]



(a) Latitude, longitude, and altitude versus time.

Figure 12. - Time histories of trajectory parameters for MA-5 mission orbit phase.

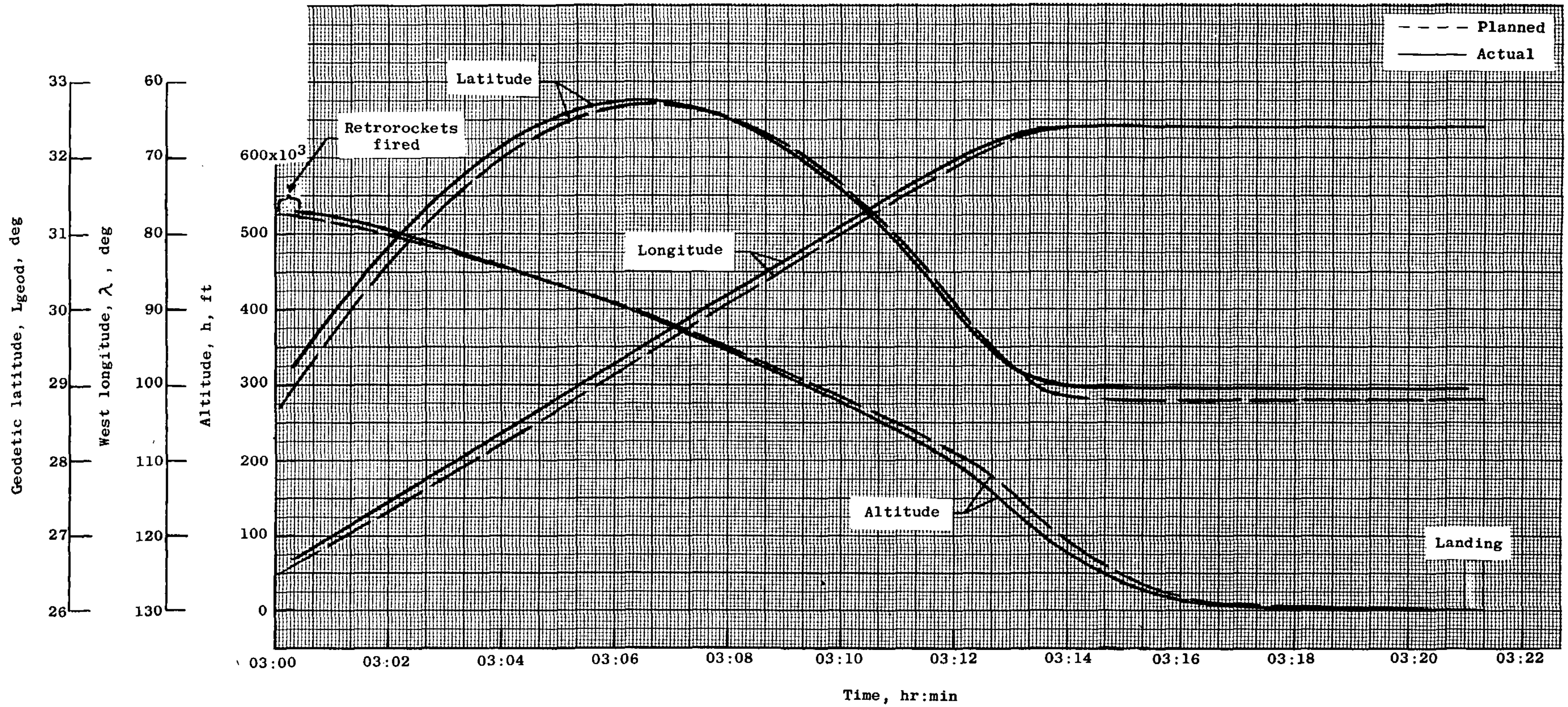
[redacted]



(b) Inertial velocity and flight-path angle versus time.

Figure 12. - Concluded.

[redacted]

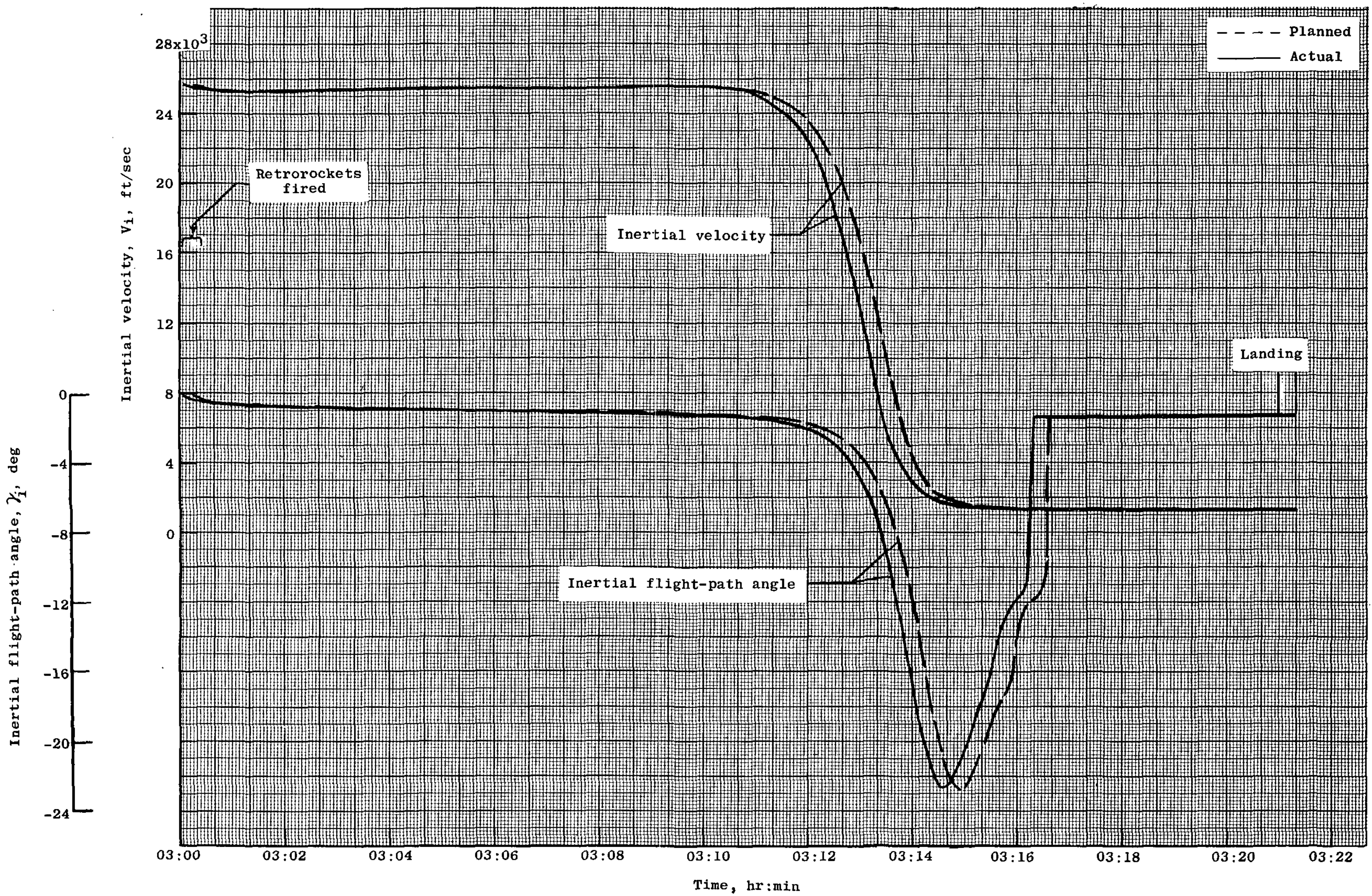


(a) Latitude, longitude, and altitude versus time.

Figure 13. - Time histories of trajectory parameters for MA-5 mission reentry phase.

[redacted]

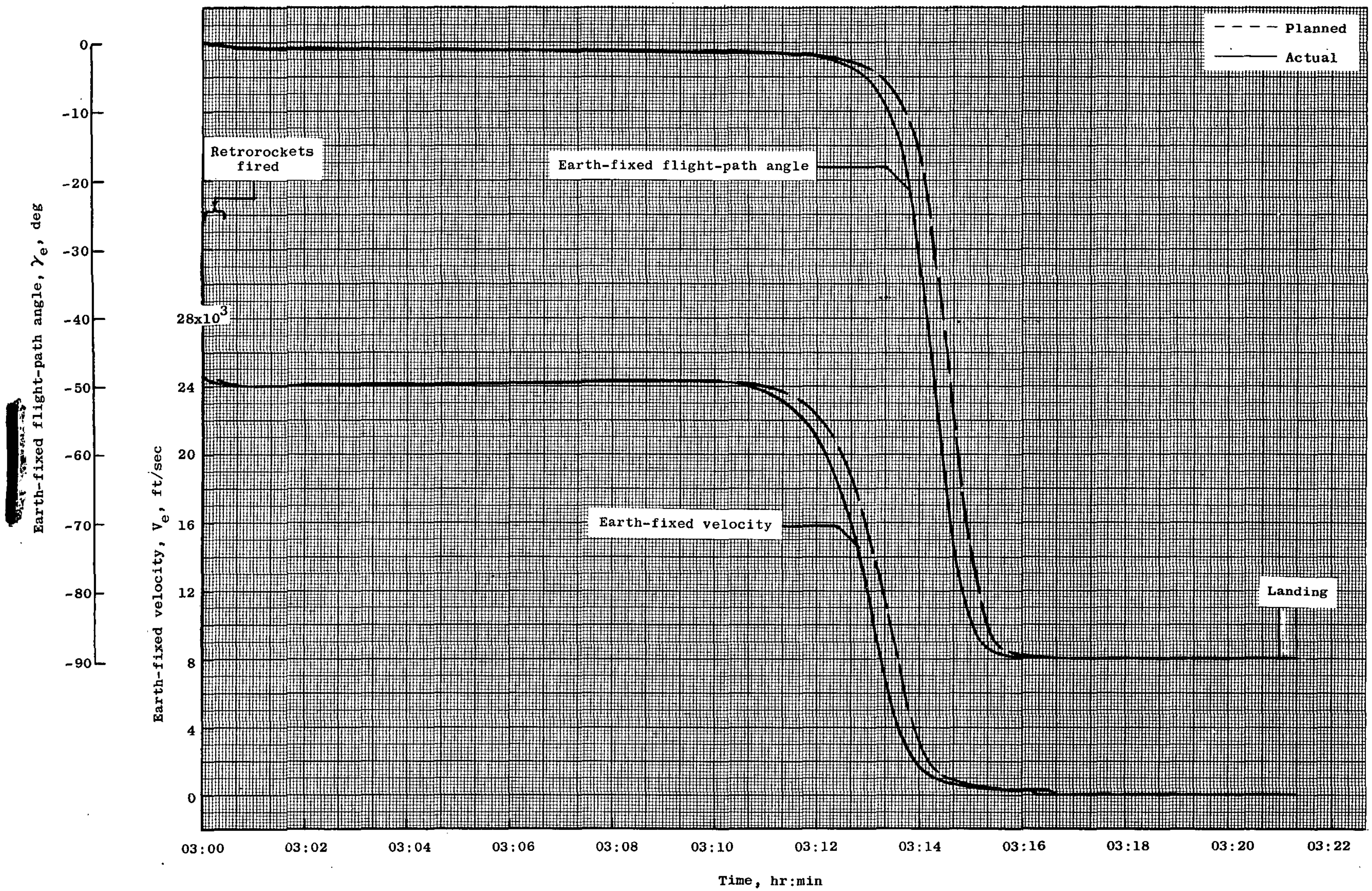
[redacted]



(b) Inertial velocity and flight-path angle versus time.

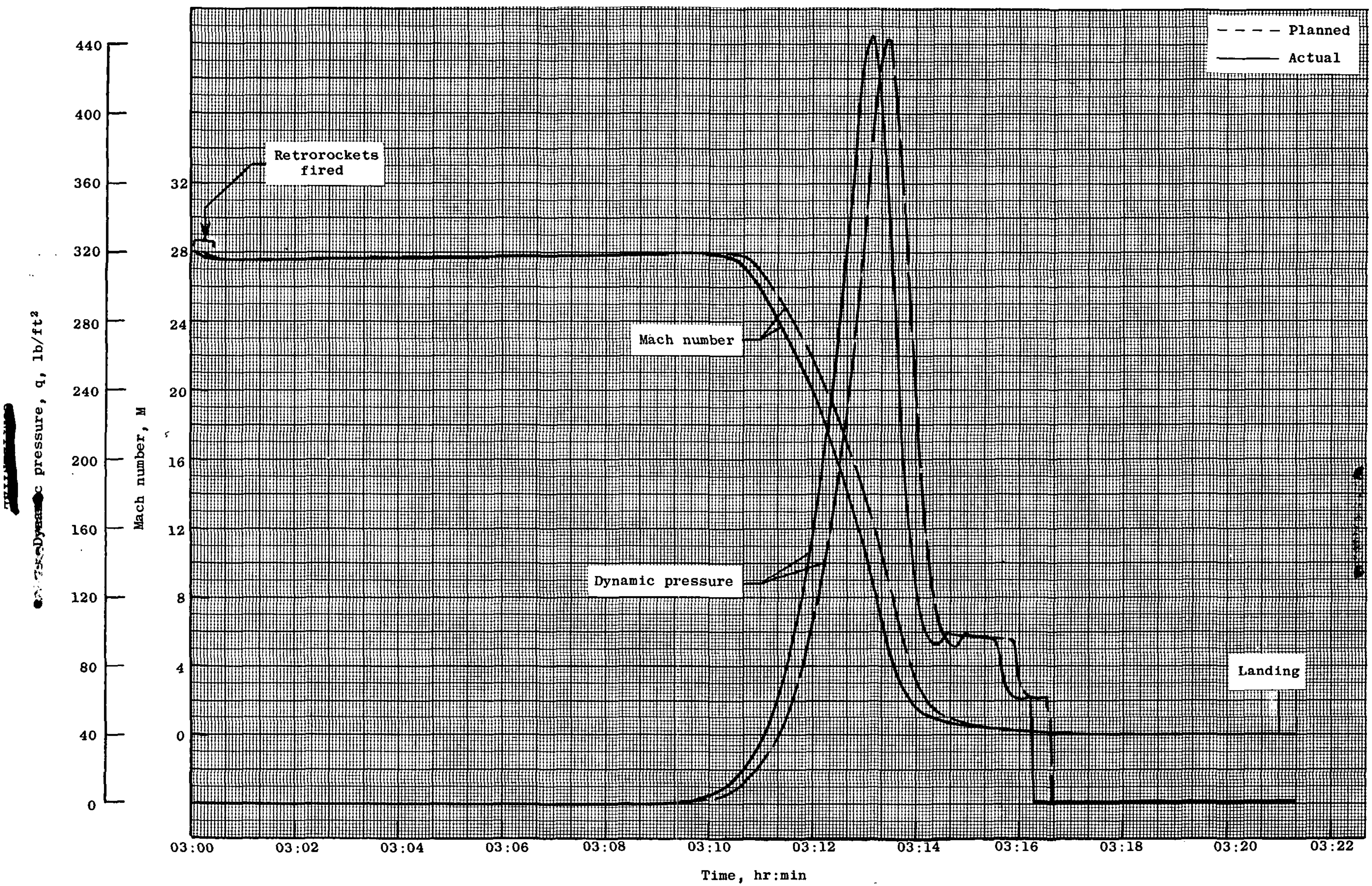
Figure 13. - Continued.

[redacted]



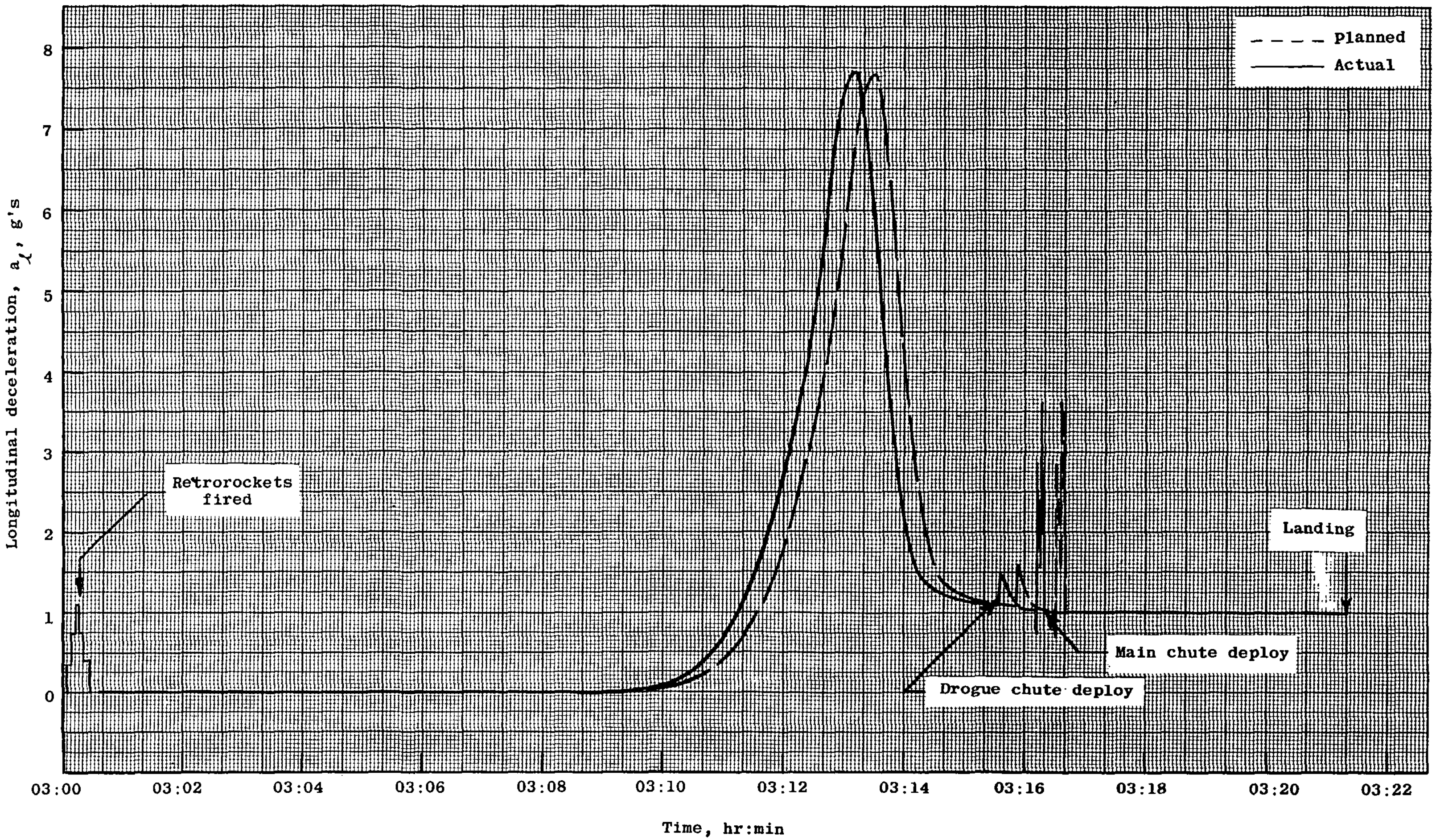
(c) Earth-fixed velocity and flight-path angle versus time.

Figure 13. - Continued.



(d) Dynamic pressure and Mach number versus time.

Figure 13. - Continued.

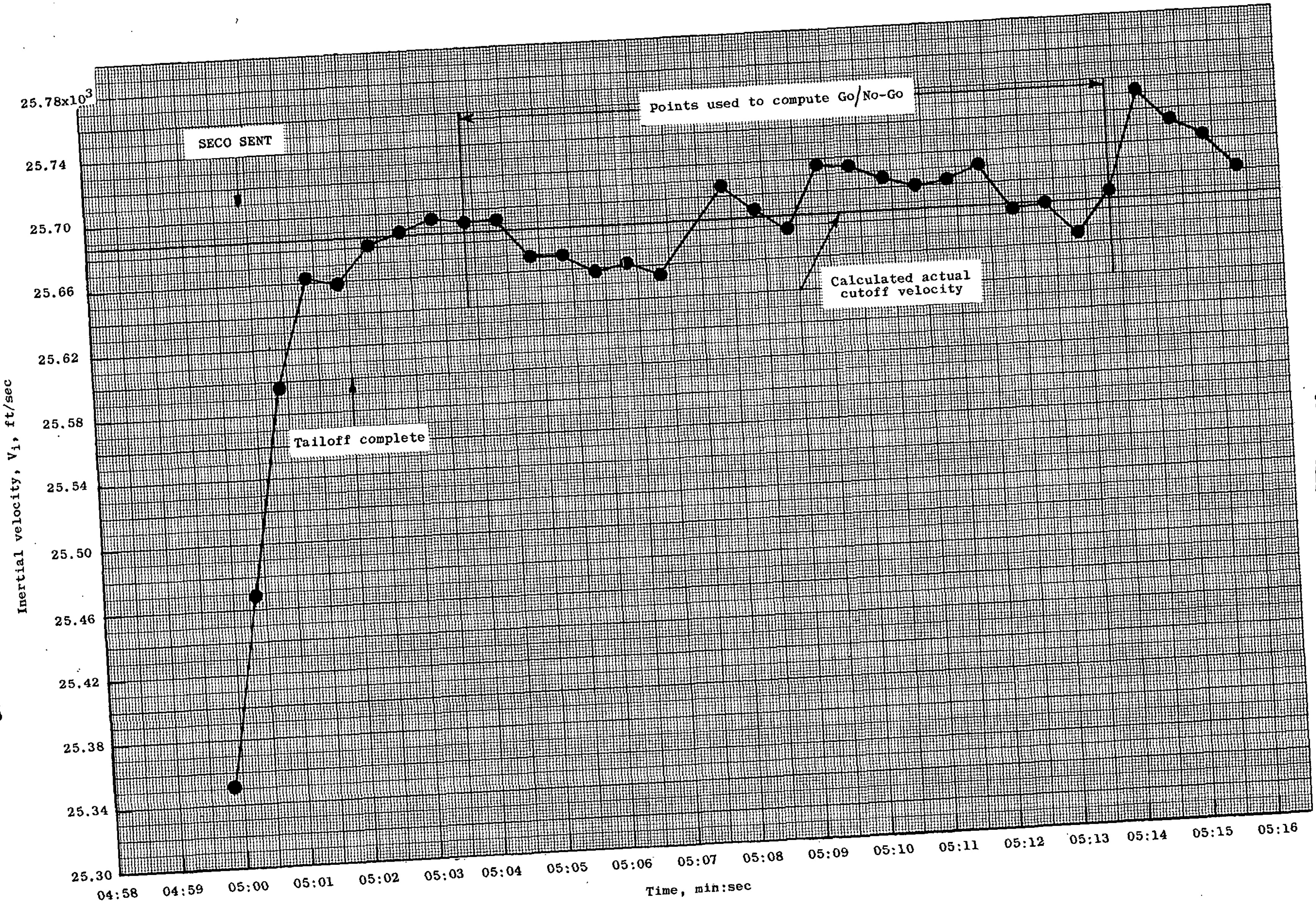


(e) Longitudinal deceleration versus time, along spacecraft Z-axis.

Figure 13 .- Concluded.

[redacted]

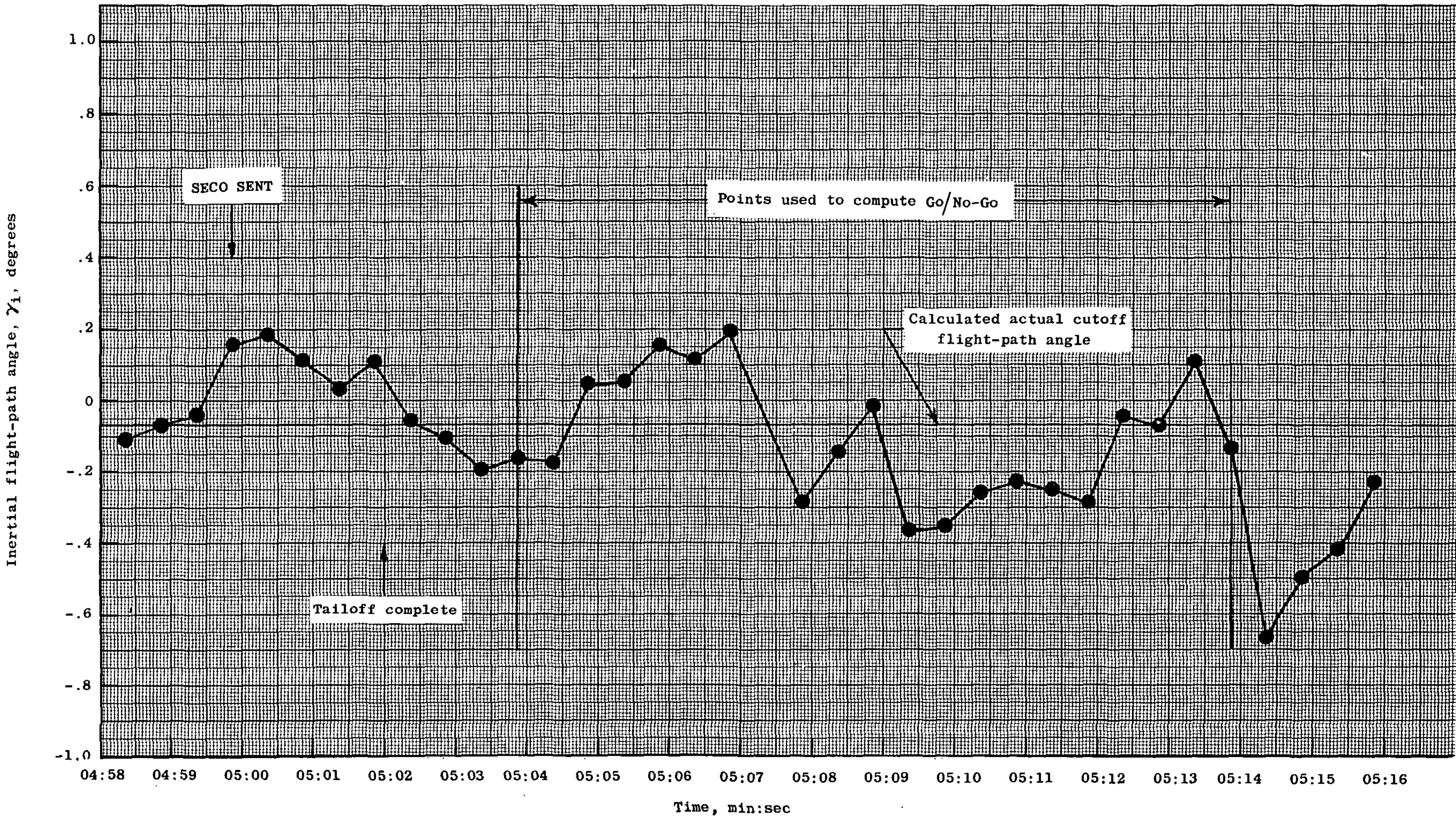
[redacted]



(a) Inertial velocity.

Figure 14. - Inertial velocity and flight-path angle in the region of cutoff using G.E.-Burroughs data.

[redacted]

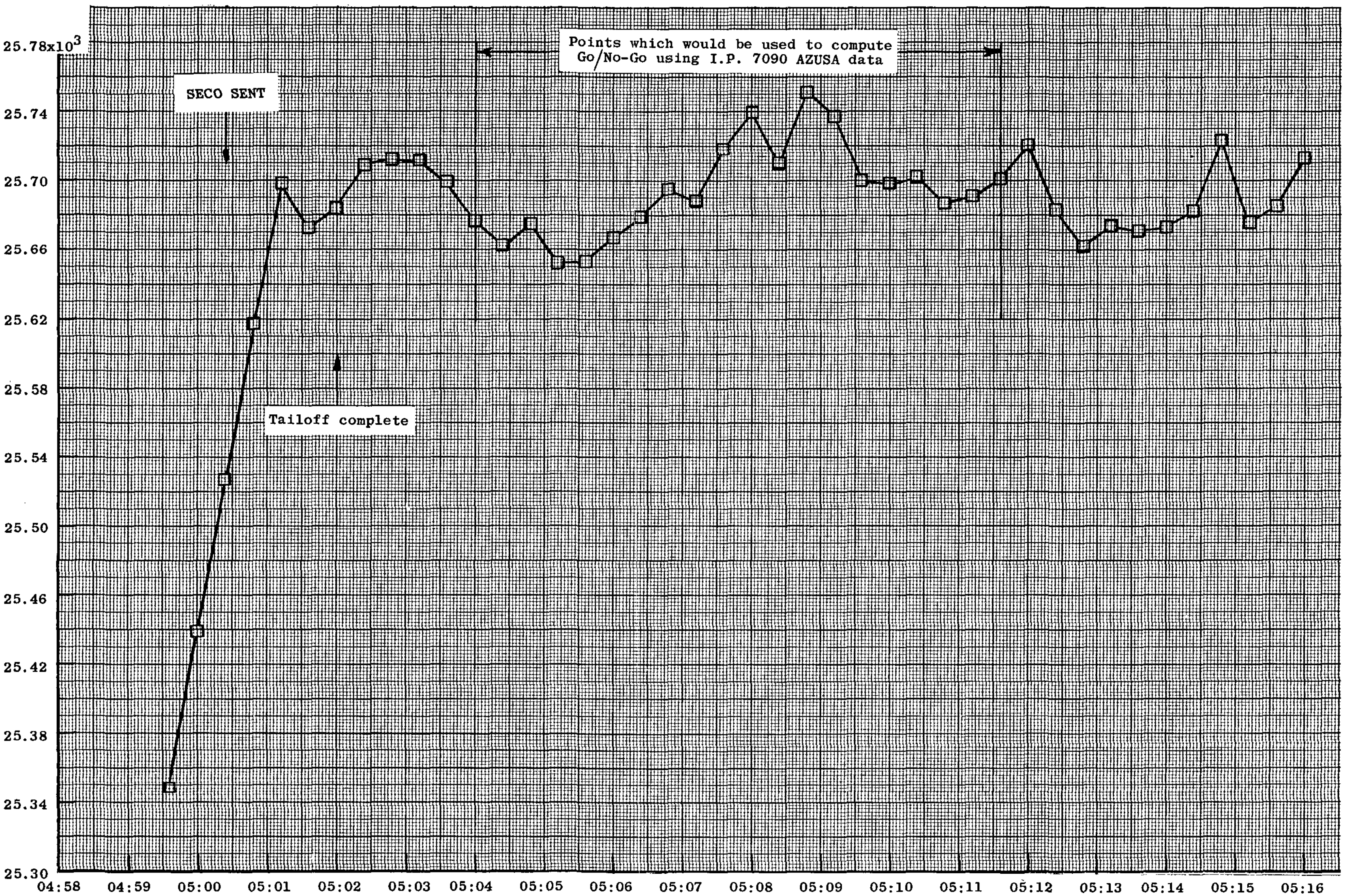


(b) Inertial flight-path angle.

Figure 14 . - Concluded.

[redacted]

[redacted]

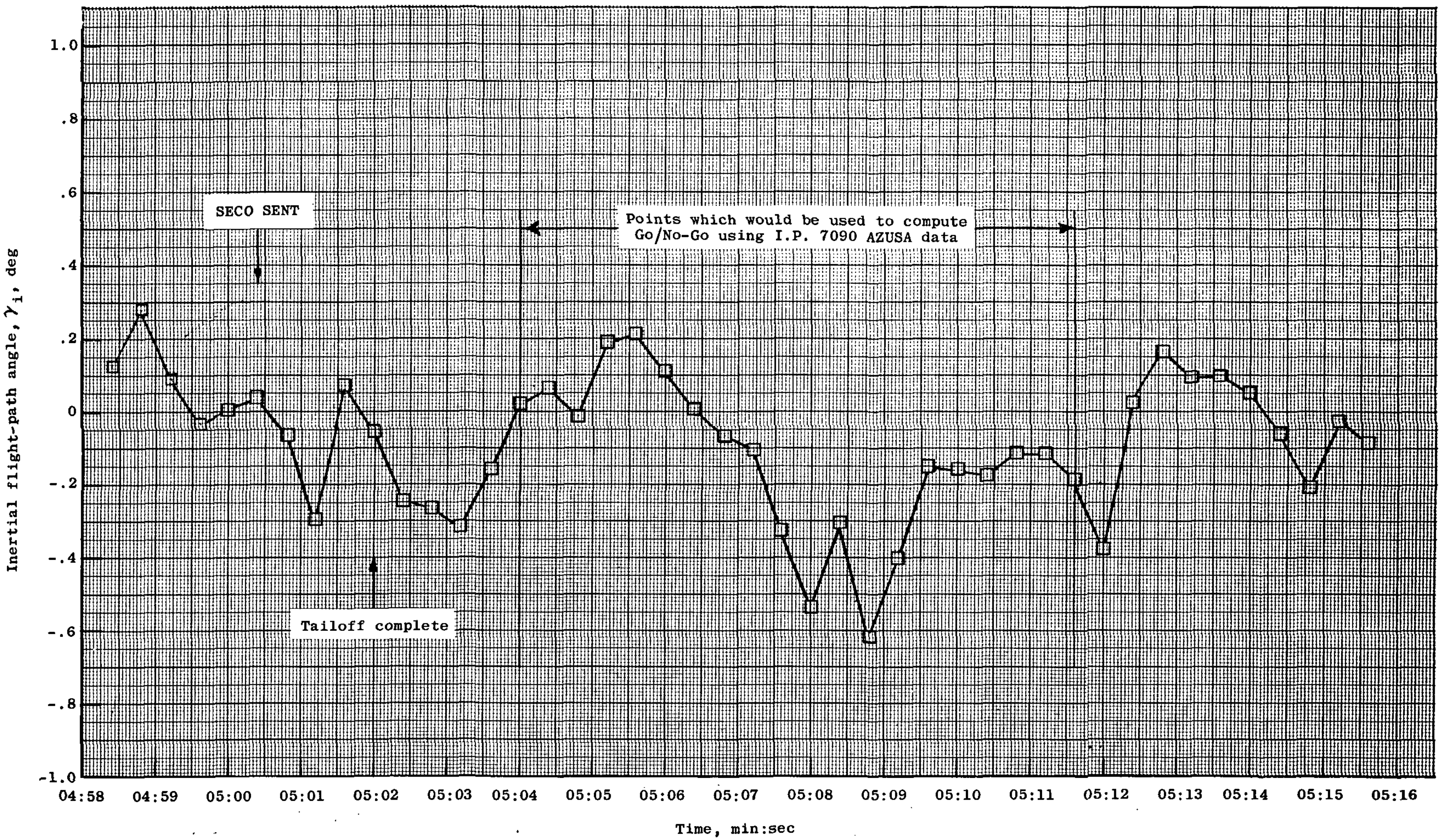


[redacted]

(a) Inertial velocity.

Figure 15. - Inertial velocity and flight-path angle in the region of cutoff using I.P. 7090 data.

[redacted]



(b) Inertial flight-path angle.

Figure 15. - Concluded.

[redacted]

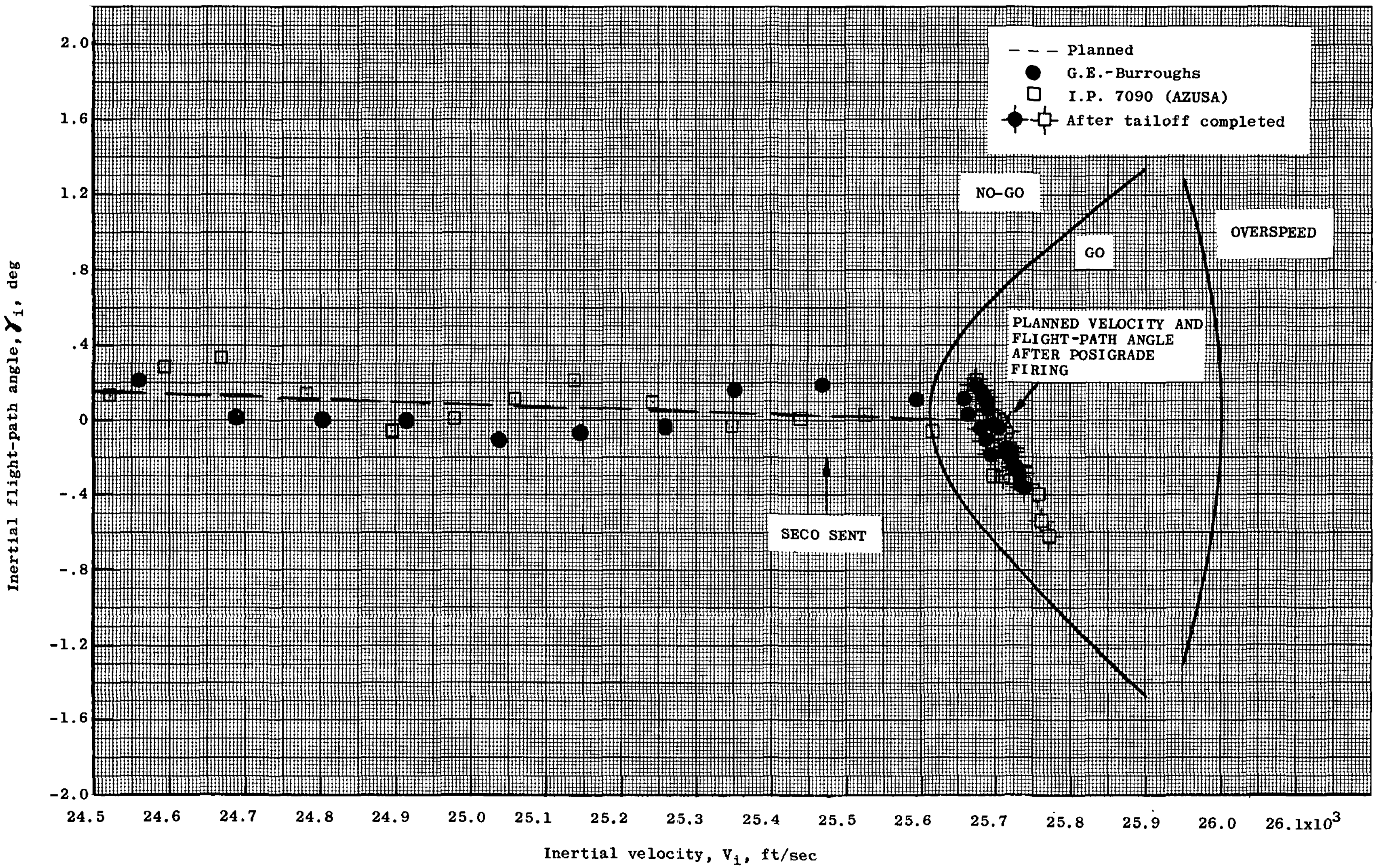


Figure 16 . - Inertial flight-path angle versus inertial velocity in the region of cutoff.

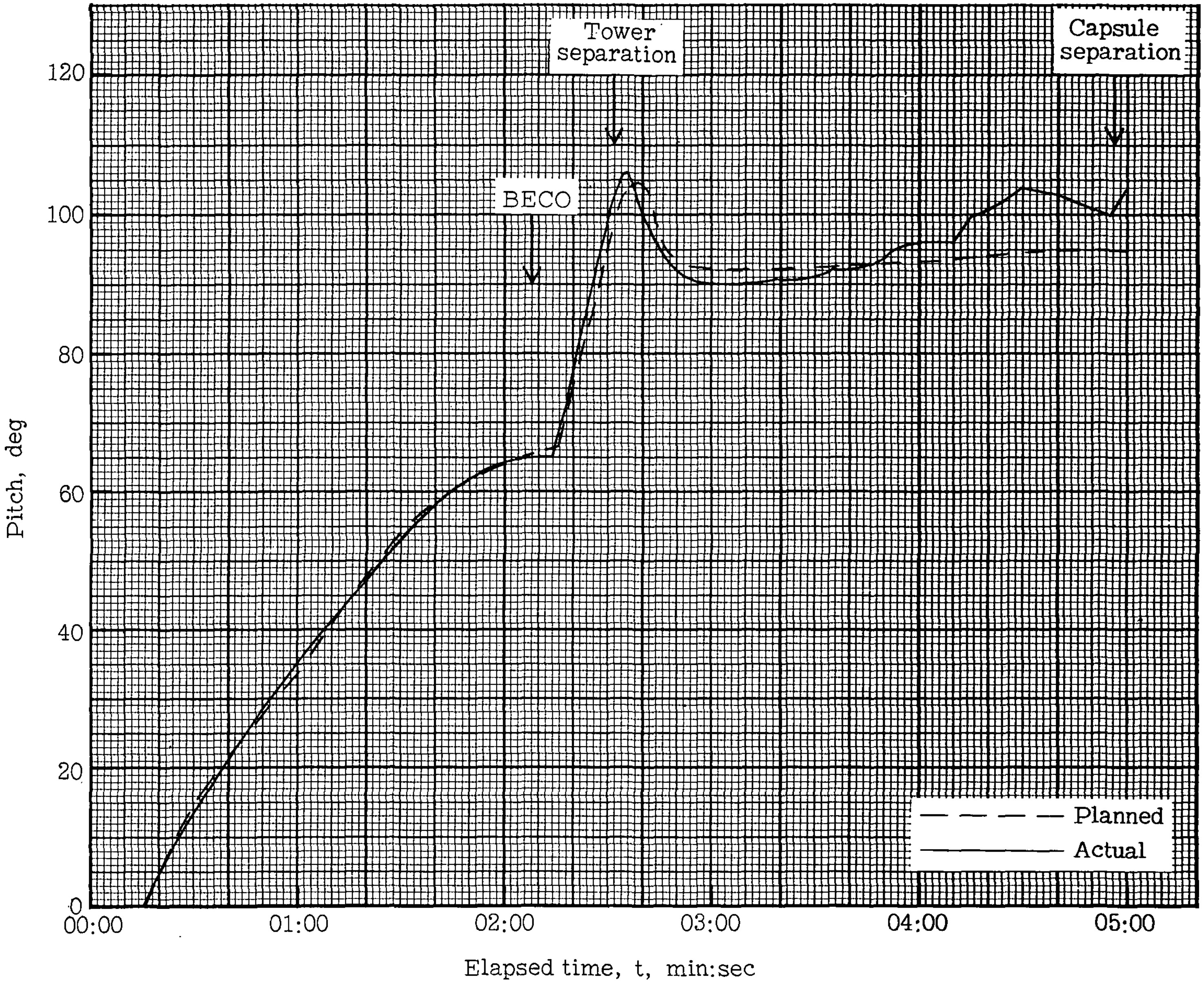
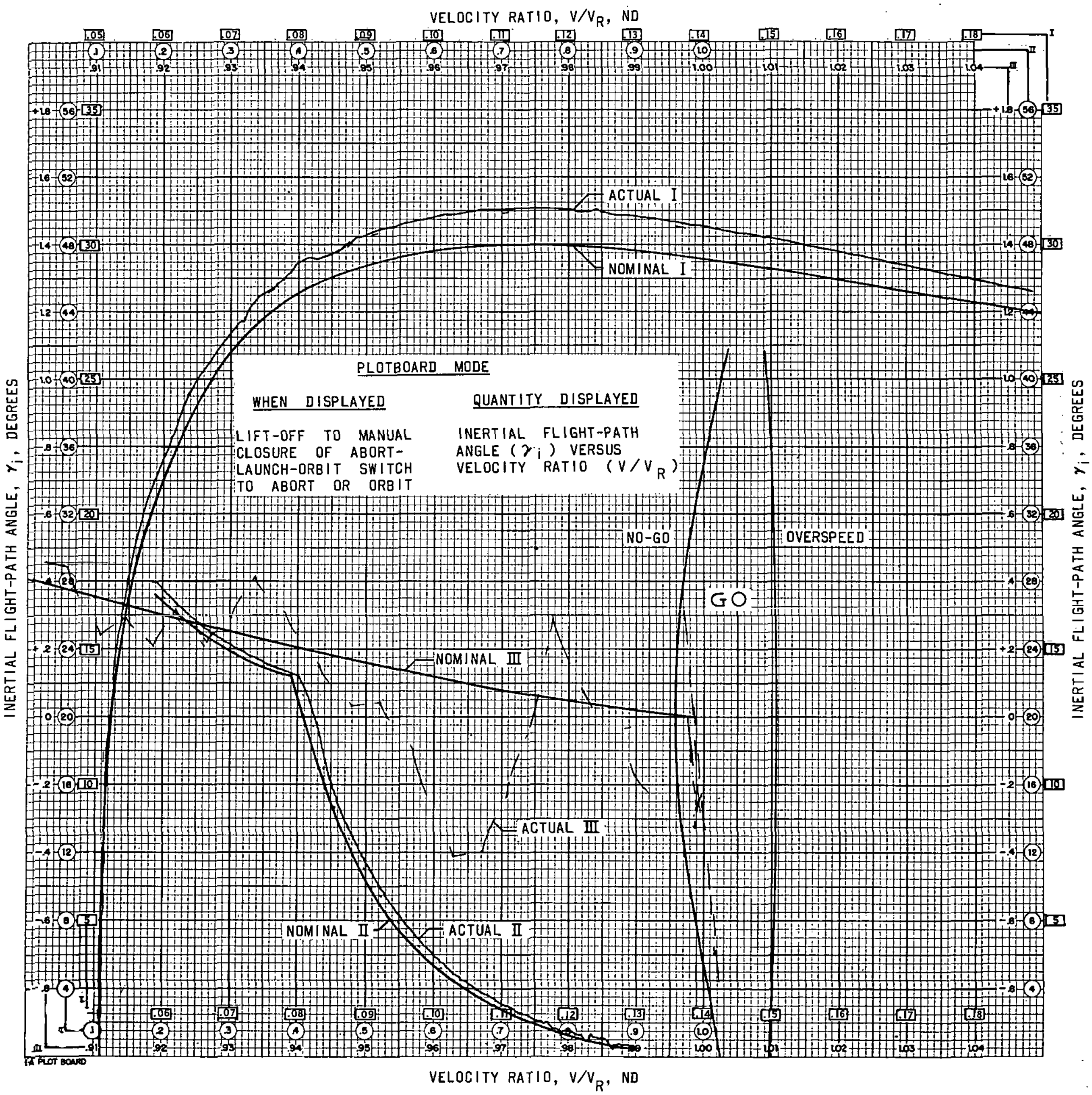
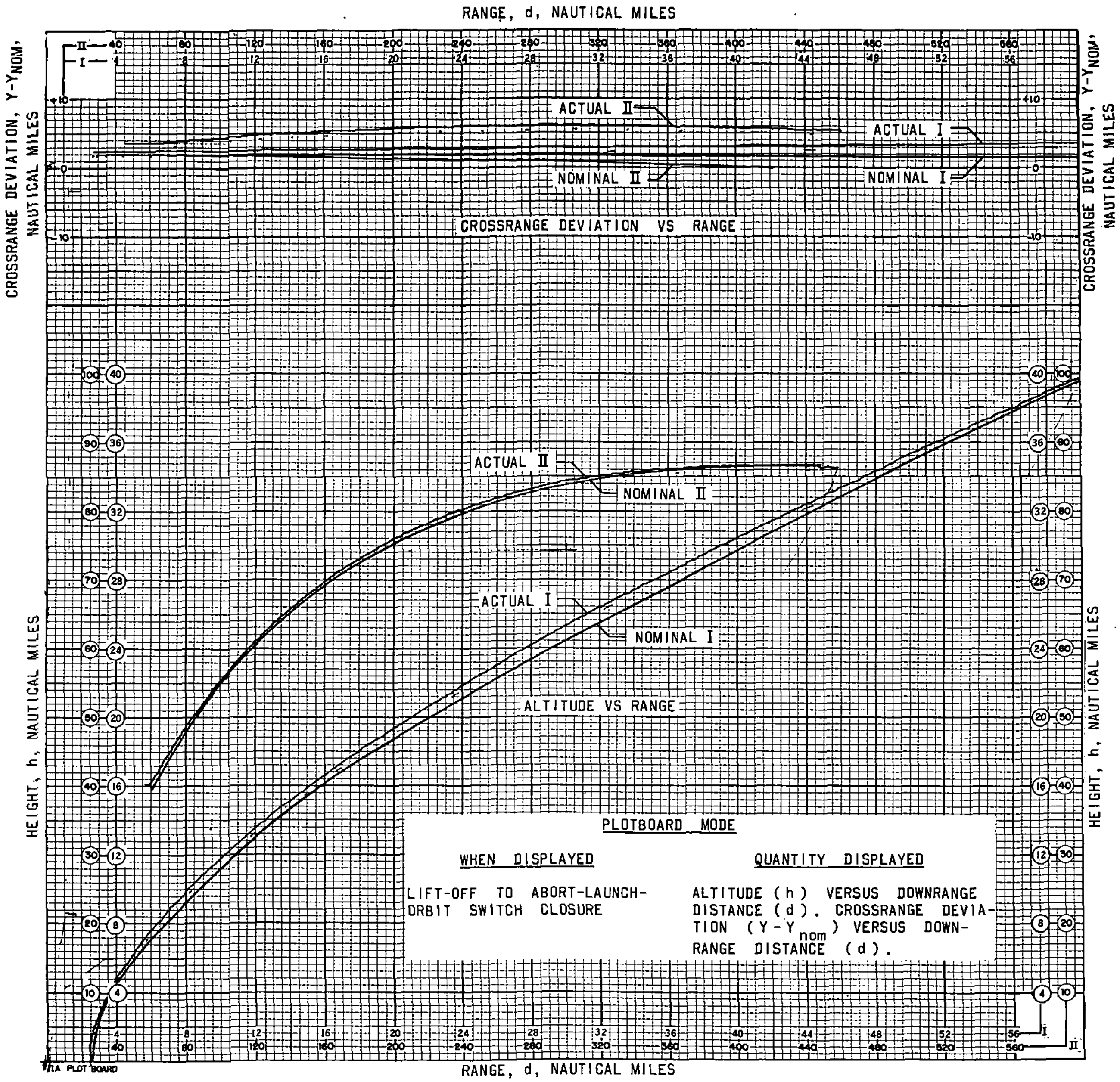


Figure 17. - Time history of pitch attitude during launch phase of the MA-4 mission compared with the nominal.



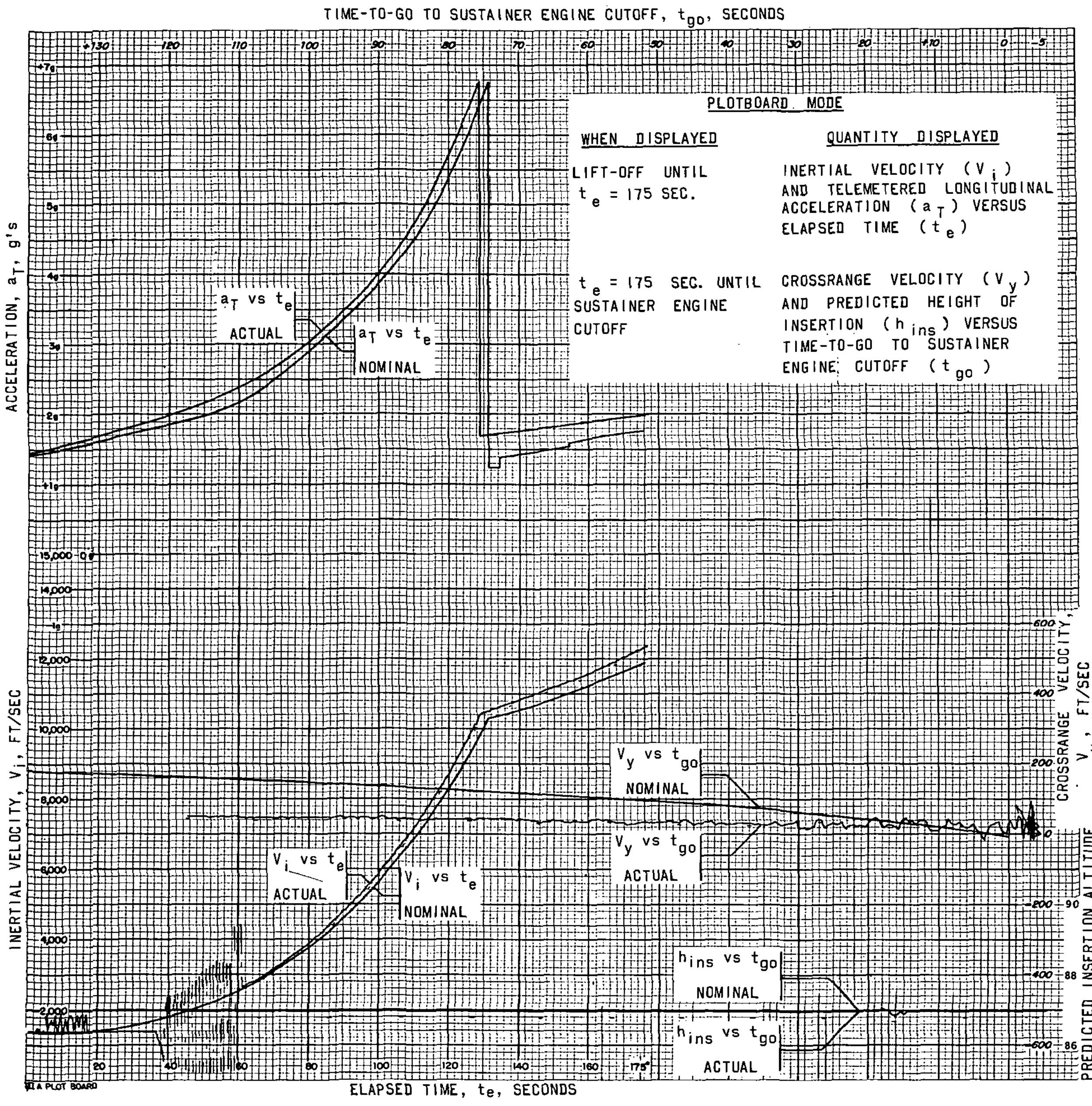
(a) PLOTBOARD I A. VELOCITY RATIO VERSUS INERTIAL FLIGHT-PATH ANGLE.

FIGURE 18.- MERCURY CONTROL CENTER PLOTBOARDS FOR MA-4 MISSION (LAUNCH PHASE).



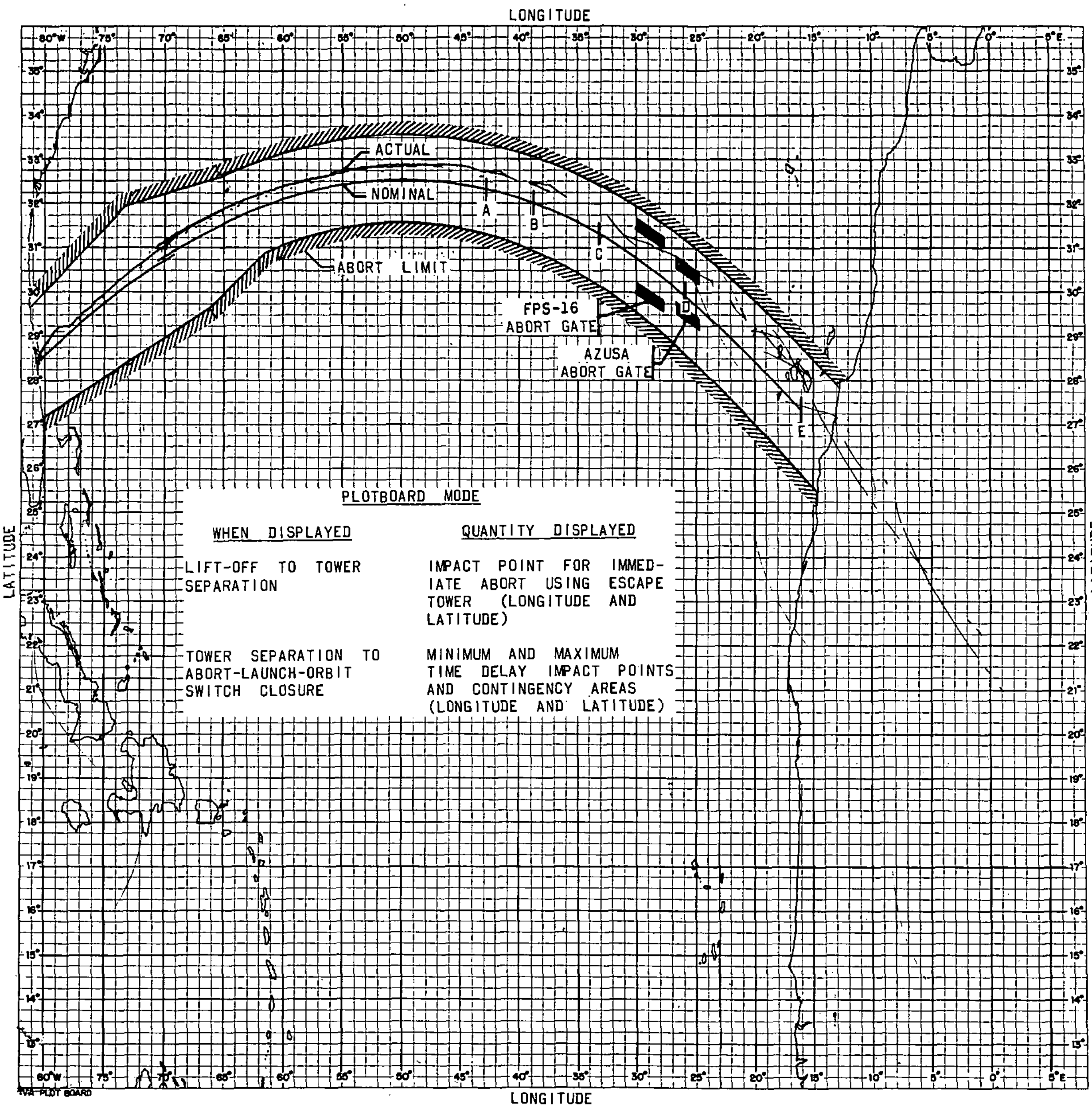
(b) PLOTBOARD IIA. CROSSRANGE DEVIATION AND HEIGHT VERSUS RANGE.

FIGURE 18.- CONTINUED.



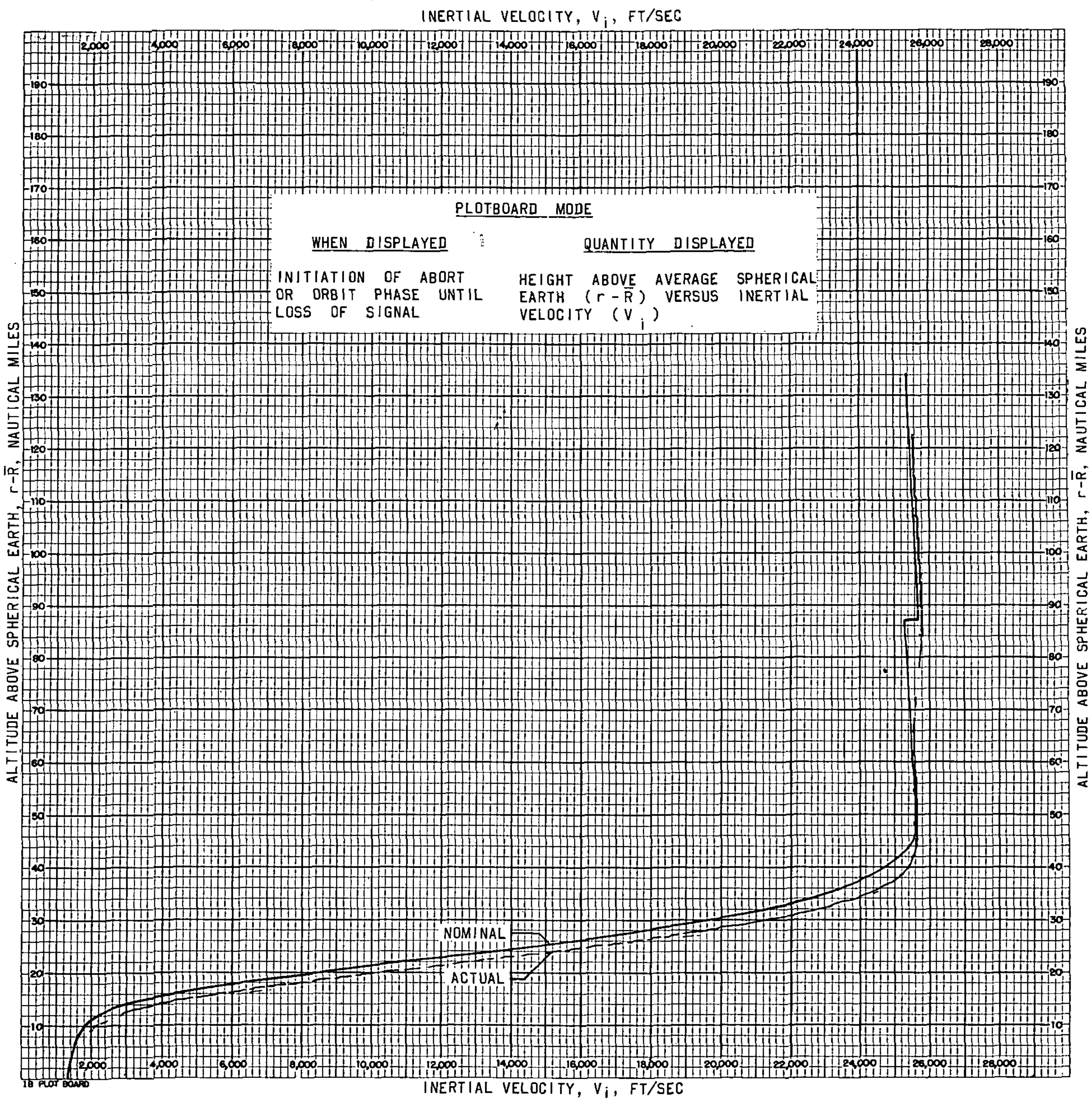
(c) PLOTBOARD III A. INERTIAL VELOCITY AND LONGITUDINAL ACCELERATION VERSUS ELAPSED TIME, AND CROSSRANGE VELOCITY AND PREDICTED INSERTION HEIGHT VERSUS TIME-TO-GO TO SUSTAINER ENGINE CUTOFF.

FIGURE 18.- CONTINUED.



(d) PLOTBOARD IV A. PREDICTED IMPACT POINTS FOR LAUNCH PHASE ABORTS.

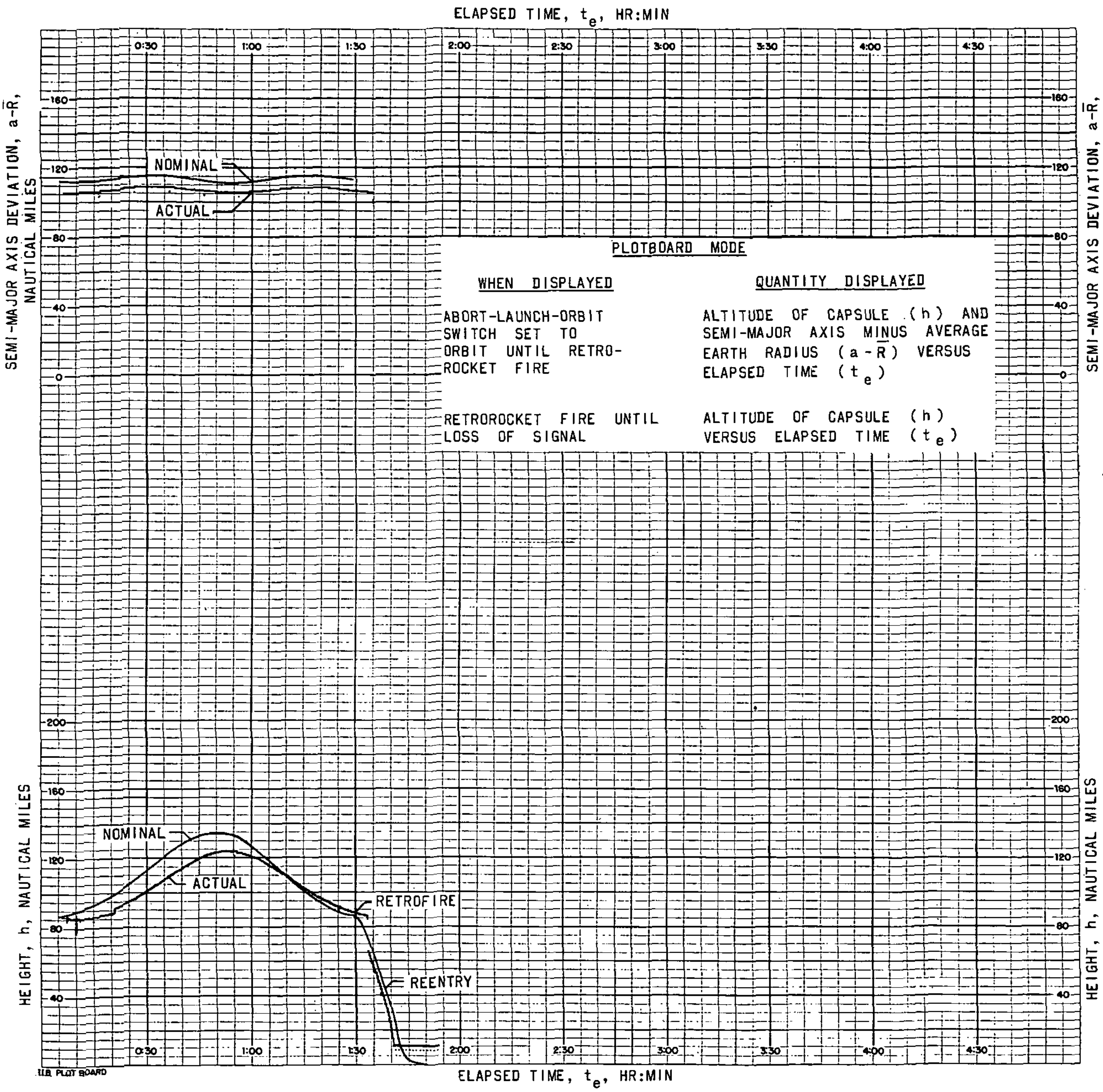
FIGURE 18.- CONCLUDED.



(a) PLOTBOARD IB. HEIGHT ABOVE EARTH VERSUS INERTIAL VELOCITY.

FIGURE 19. - MERCURY CONTROL CENTER PLOTBOARDS FOR MA-4 MISSION (ORBIT PHASE).

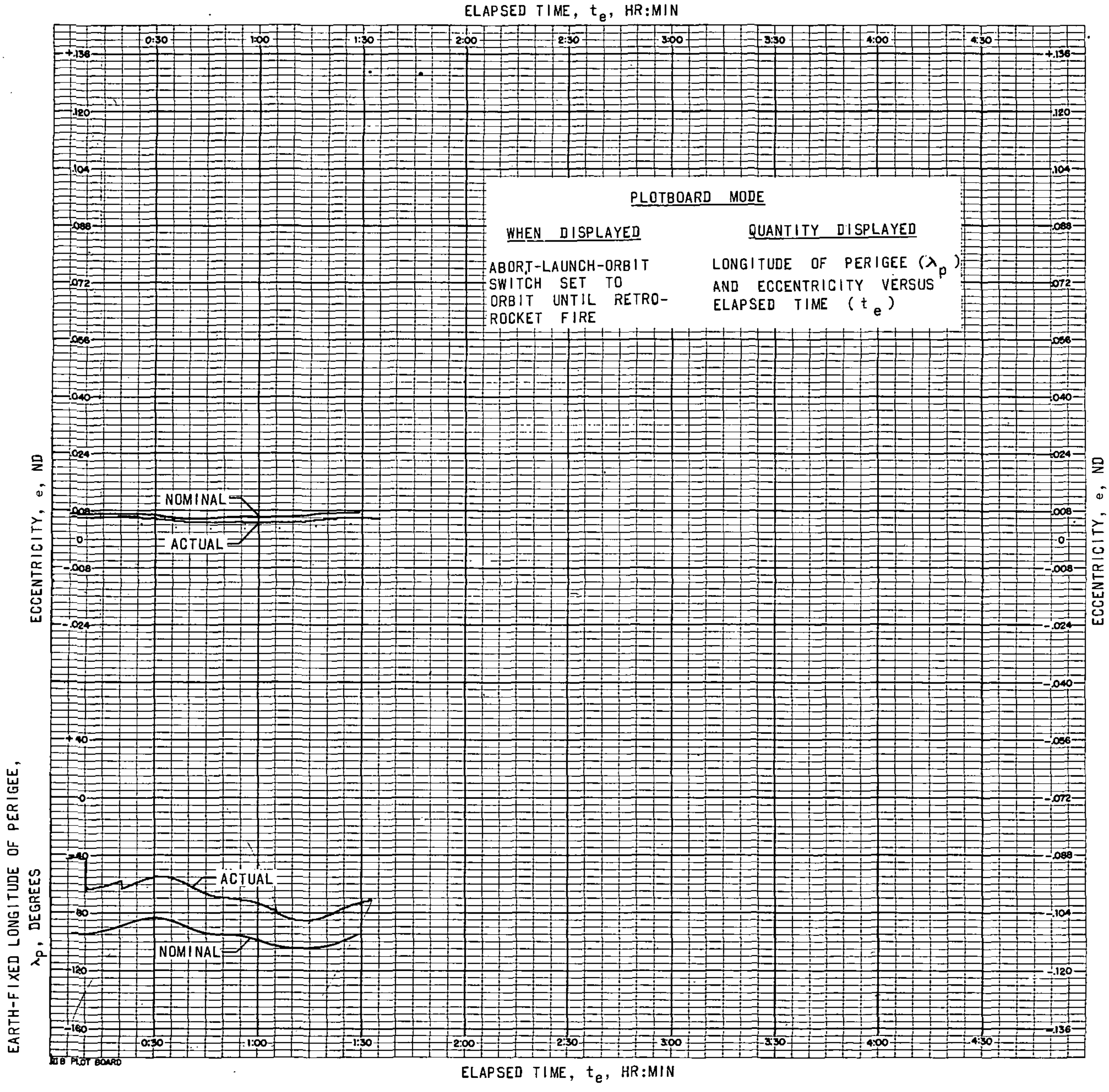
CONFIDENTIAL



(b) PLOTBOARD IIB. SEMI-MAJOR AXIS DEVIATION AND CAPSULE ALTITUDE VERSUS ELAPSED TIME.

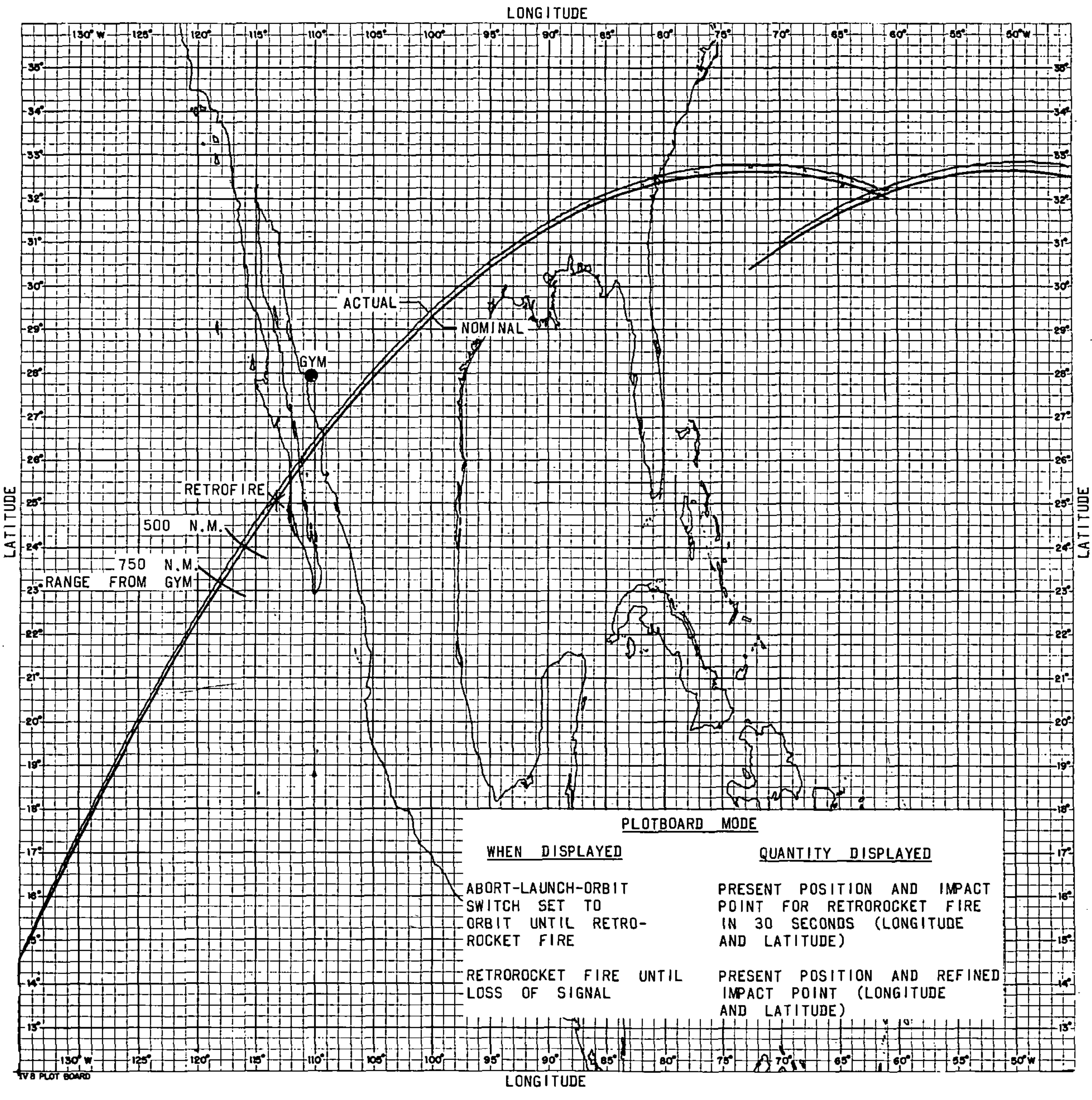
FIGURE 19. - CONTINUED.

CONFIDENTIAL



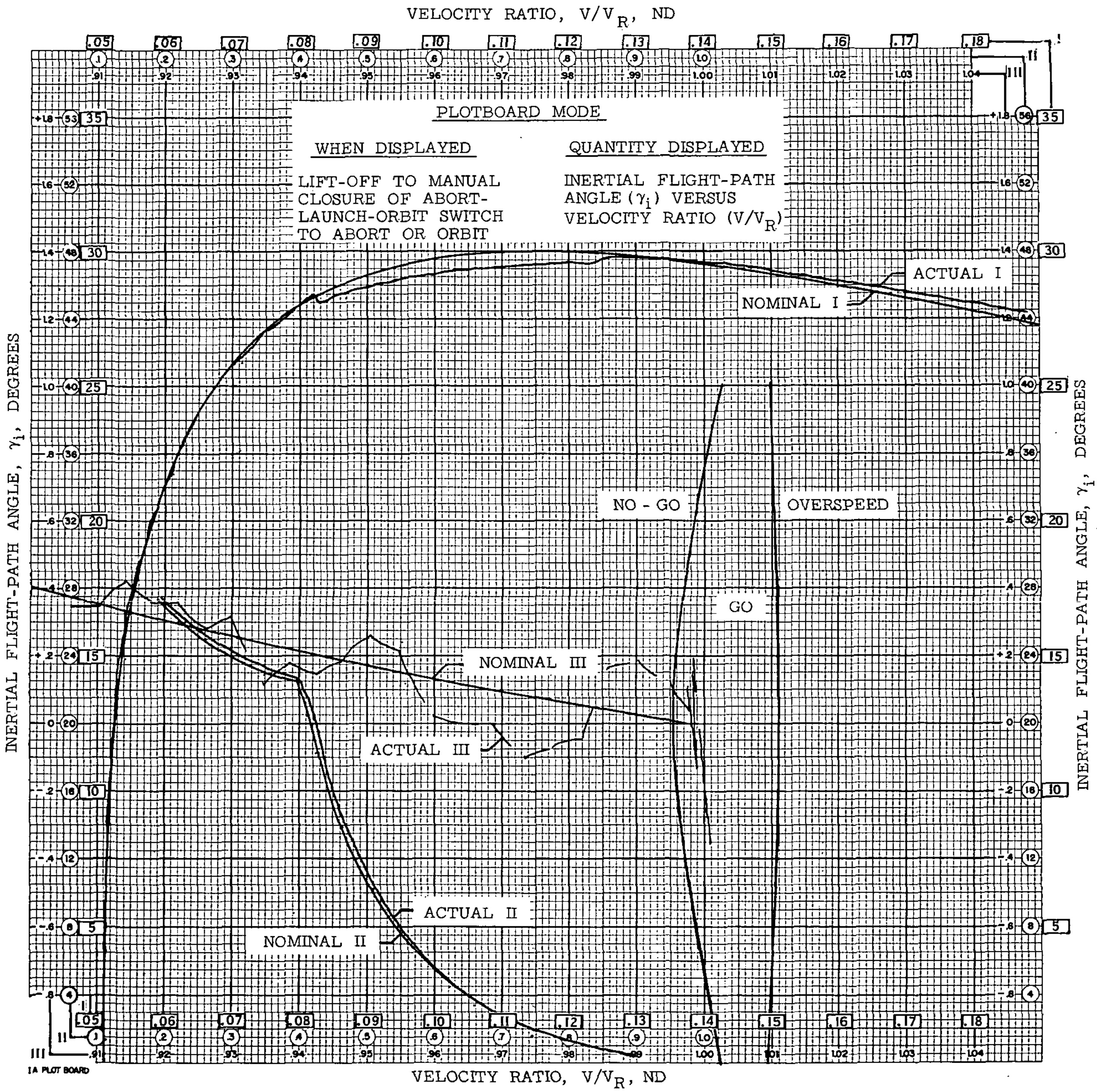
(c) PLOTBOARD IIIB. EARTH-FIXED LONGITUDE OF PERIGEE AND ECCENTRICITY VERSUS ELAPSED TIME.

FIGURE 19. - CONTINUED.



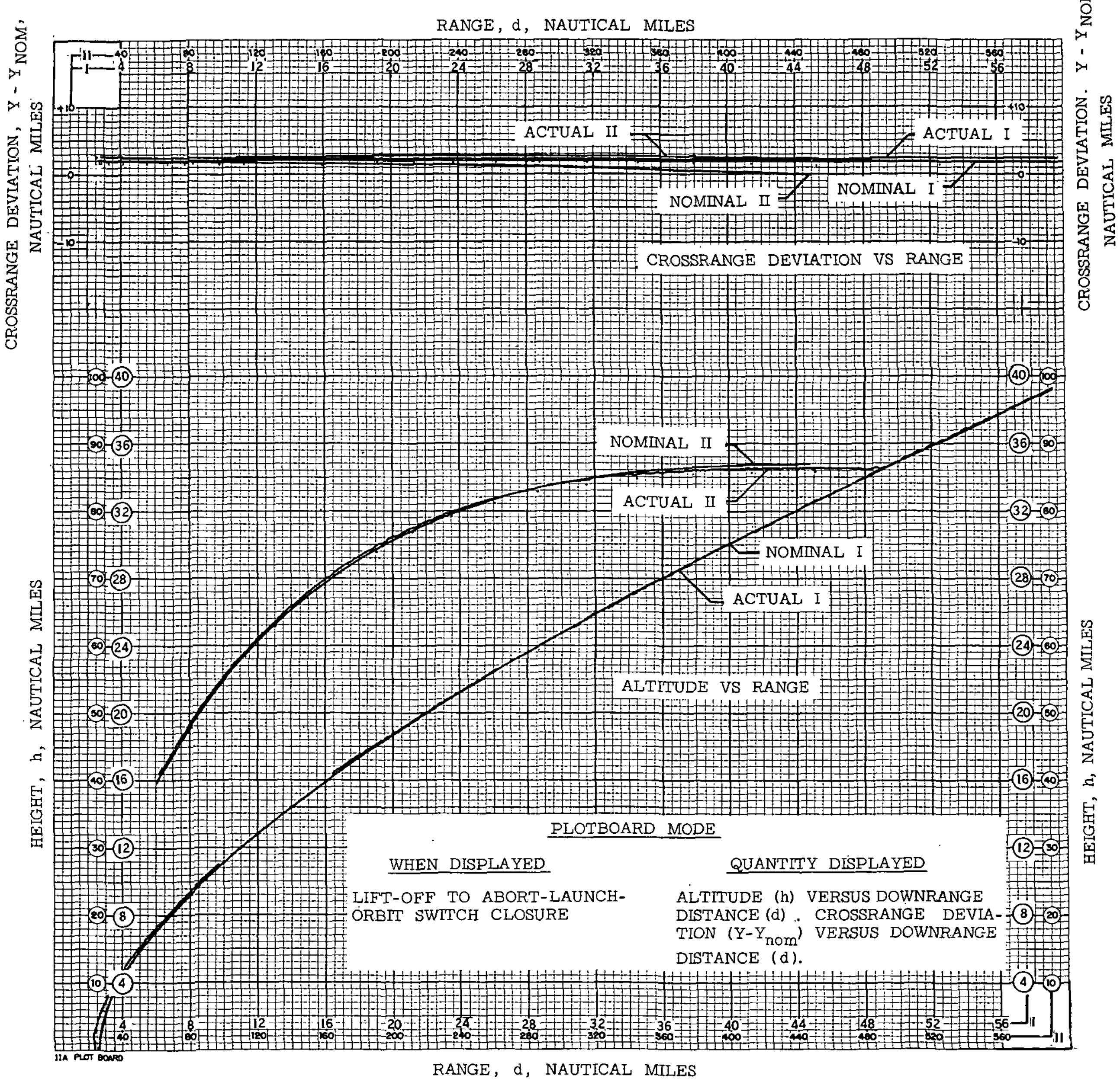
(d) PLOTBOARD IV B. PRESENT POSITION AND PREDICTED IMPACT POINT.

FIGURE 19. - CONCLUDED.



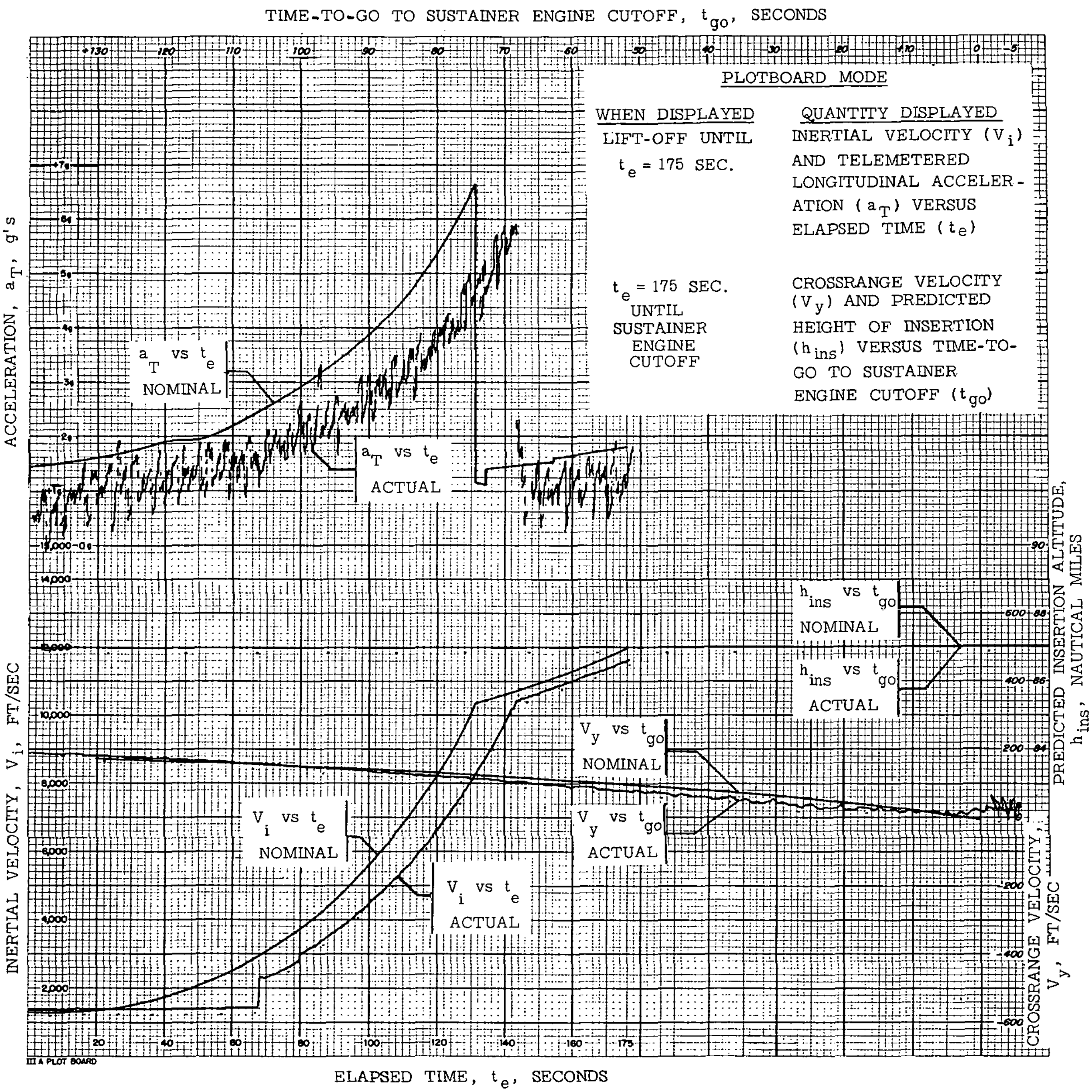
(a) Plotboard IA. Velocity ratio versus inertial flight-path angle.

Figure 20. - Mercury Control Center plotboards for MA-5 mission (launch phase).



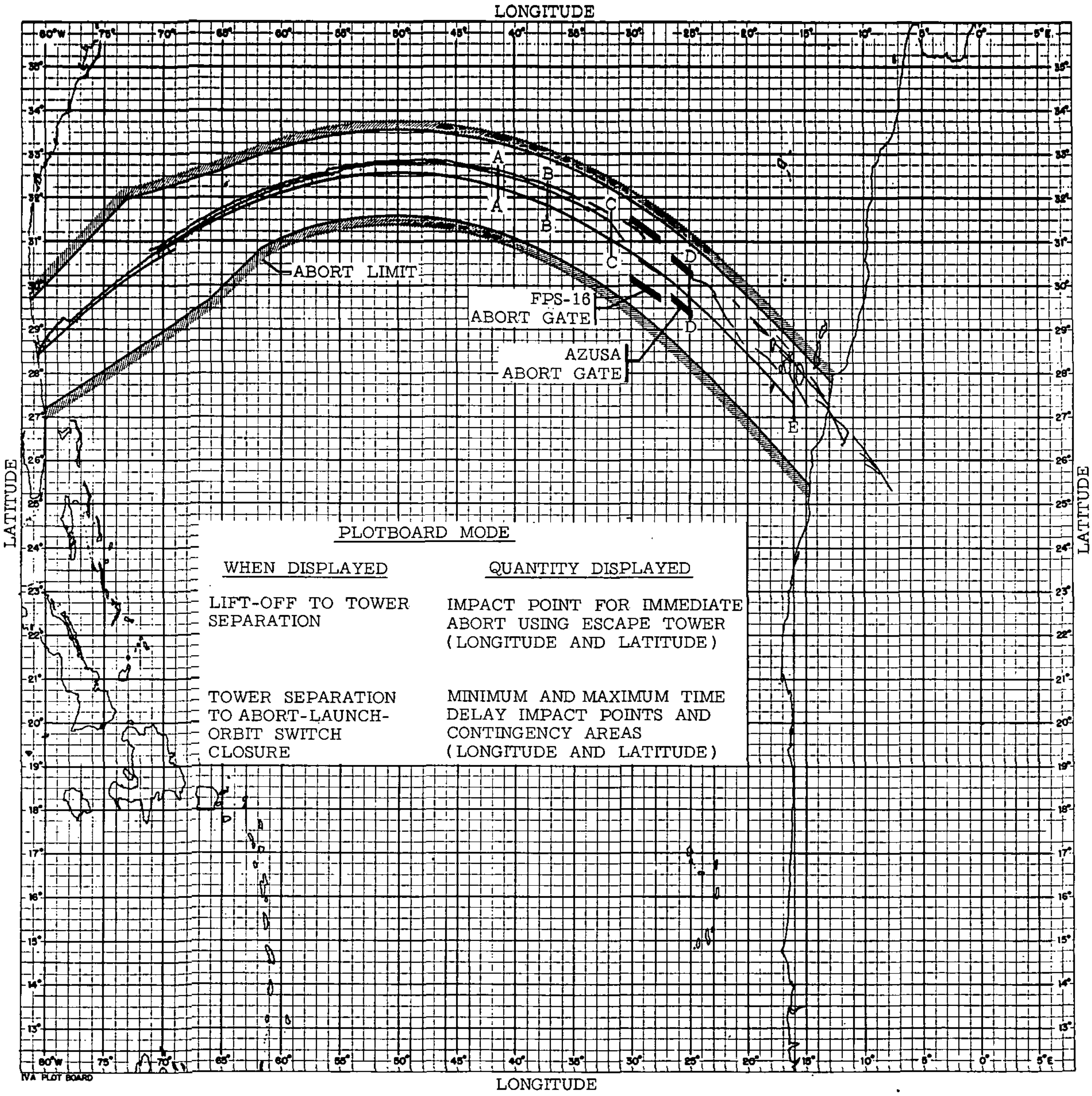
(b) Plotboard II A. Crossrange deviation and height versus range.

Figure 20. - Continued.



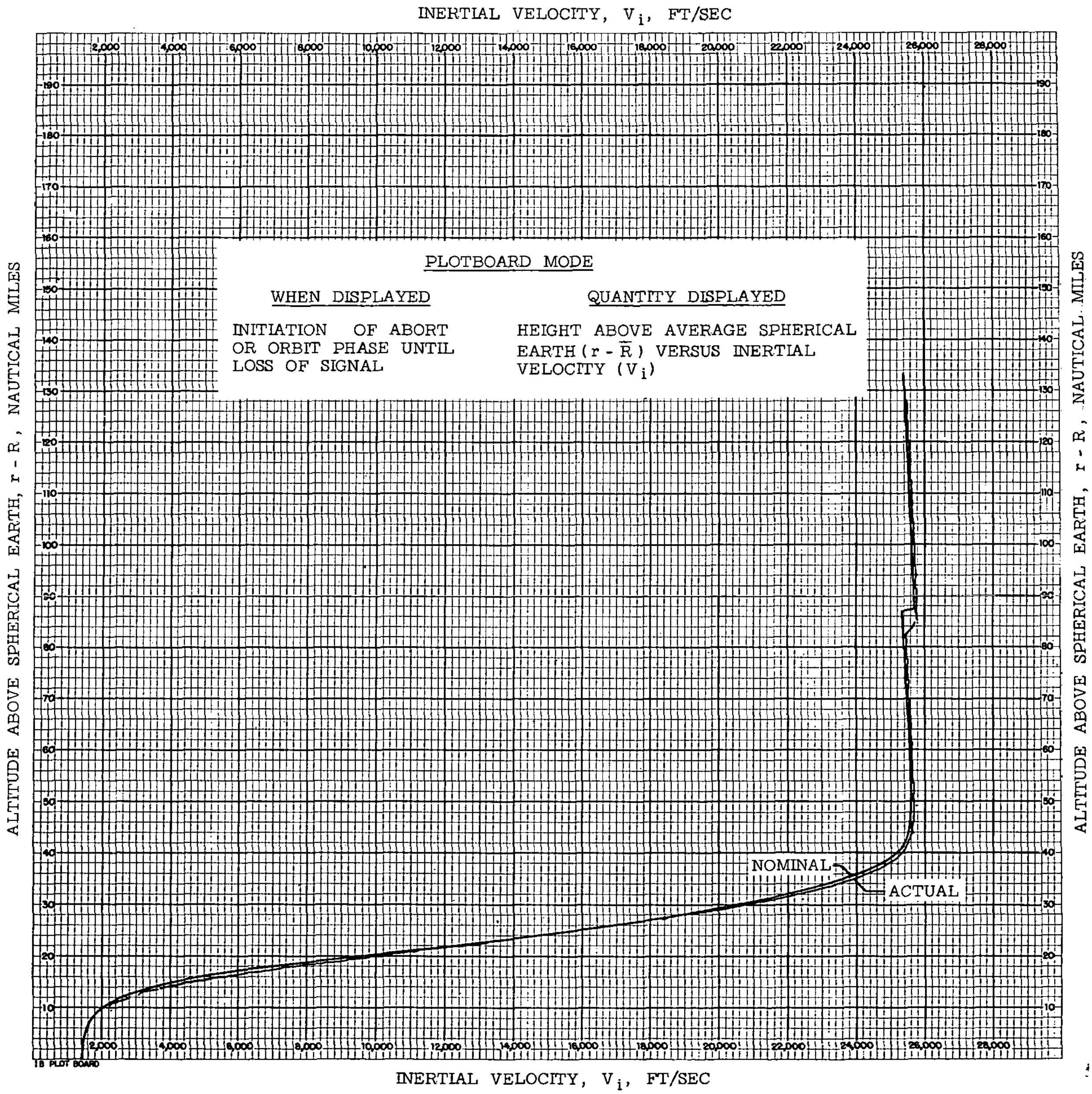
(c) Plotboard IIIA. Inertial velocity and longitudinal acceleration versus elapsed time, and crossrange velocity and predicted insertion height versus time-to-go to sustainer engine cutoff.

Figure 20. - Continued.



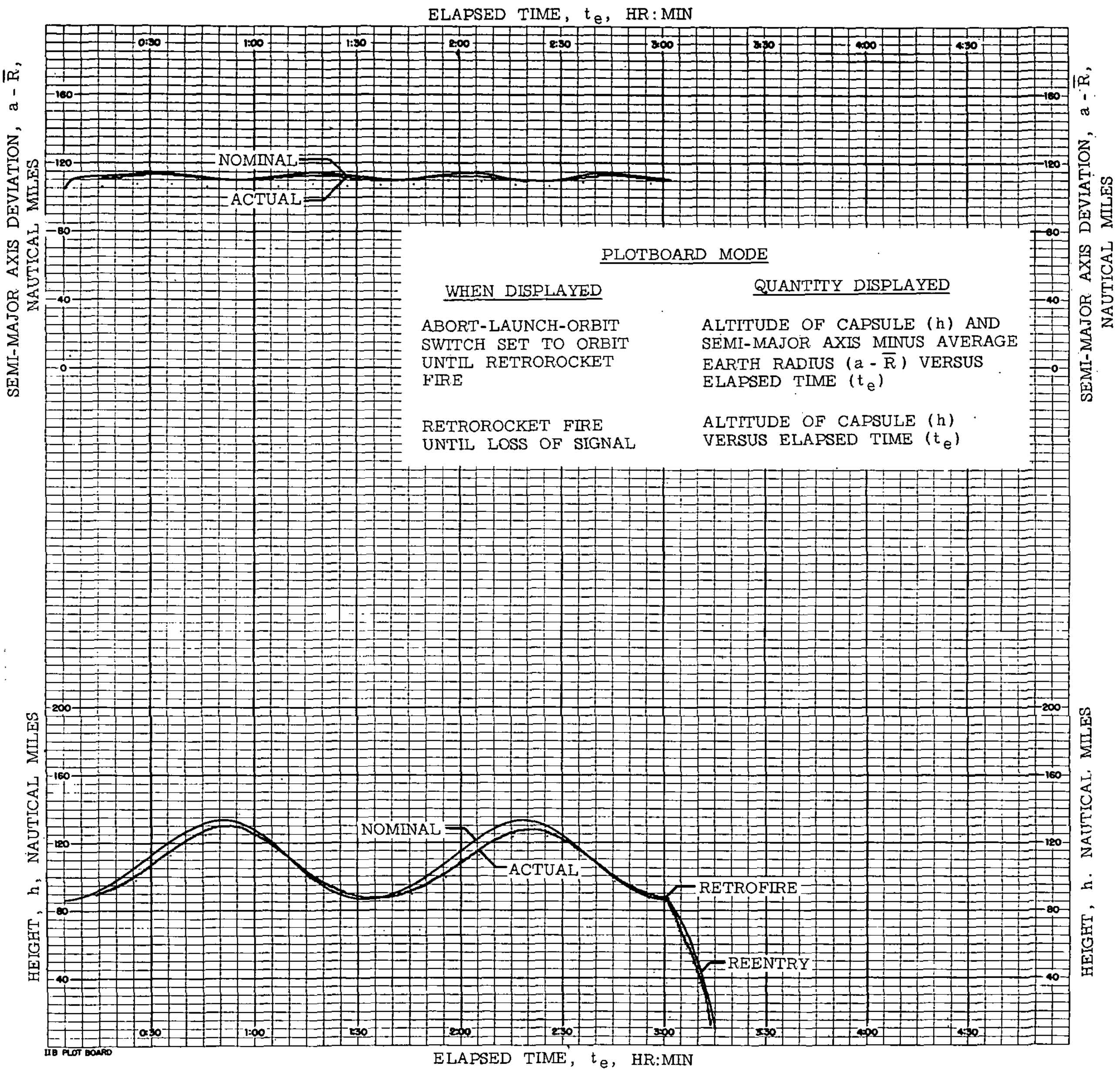
(d) Plotboard IV A. Predicted impact points for launch phase aborts.

Figure 20. - Concluded.



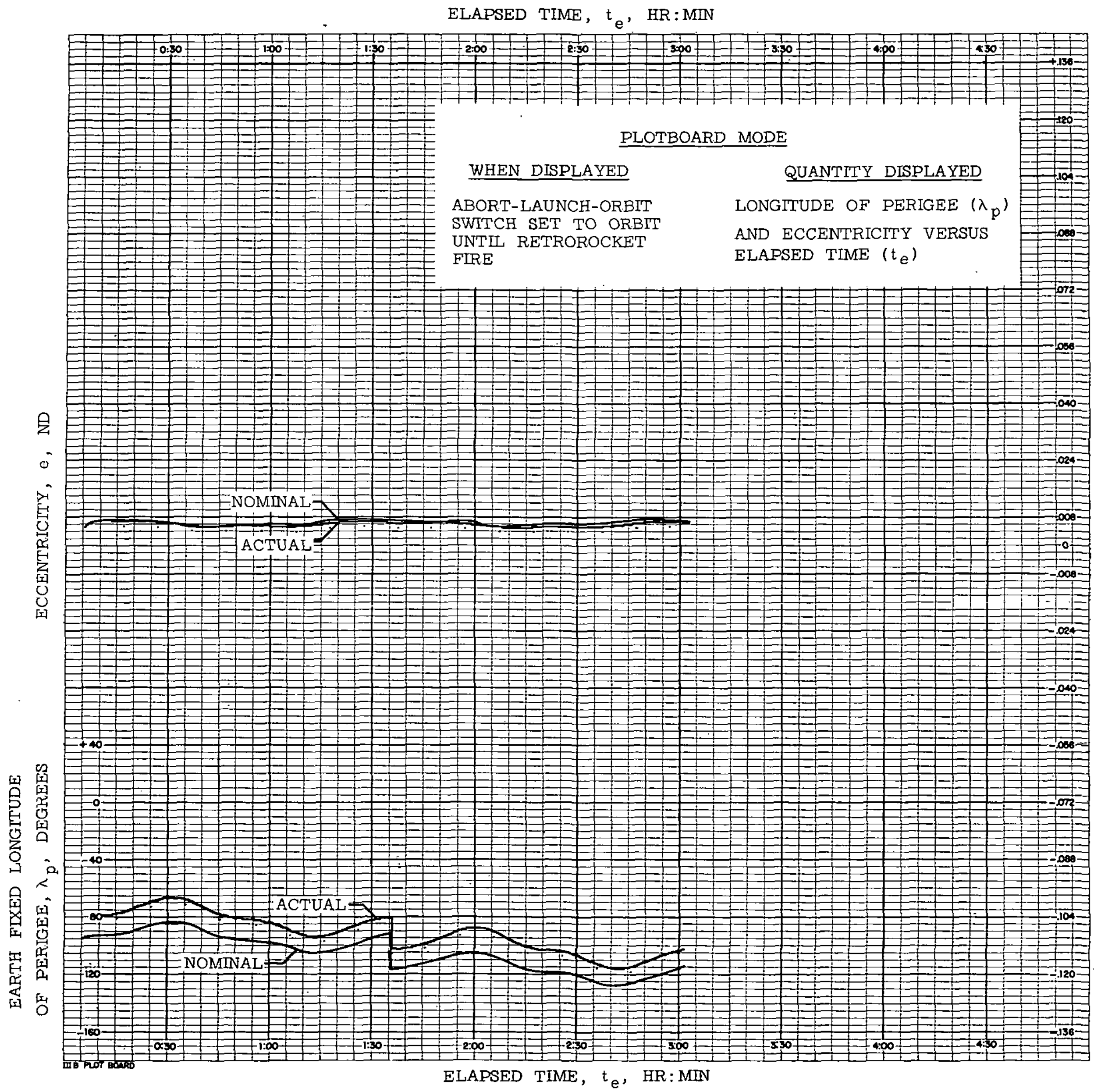
(a) Plotboard IB. Height above earth versus inertial velocity.

Figure 21. - Mercury Control Center plotboards for MA-5 mission (orbit phase).



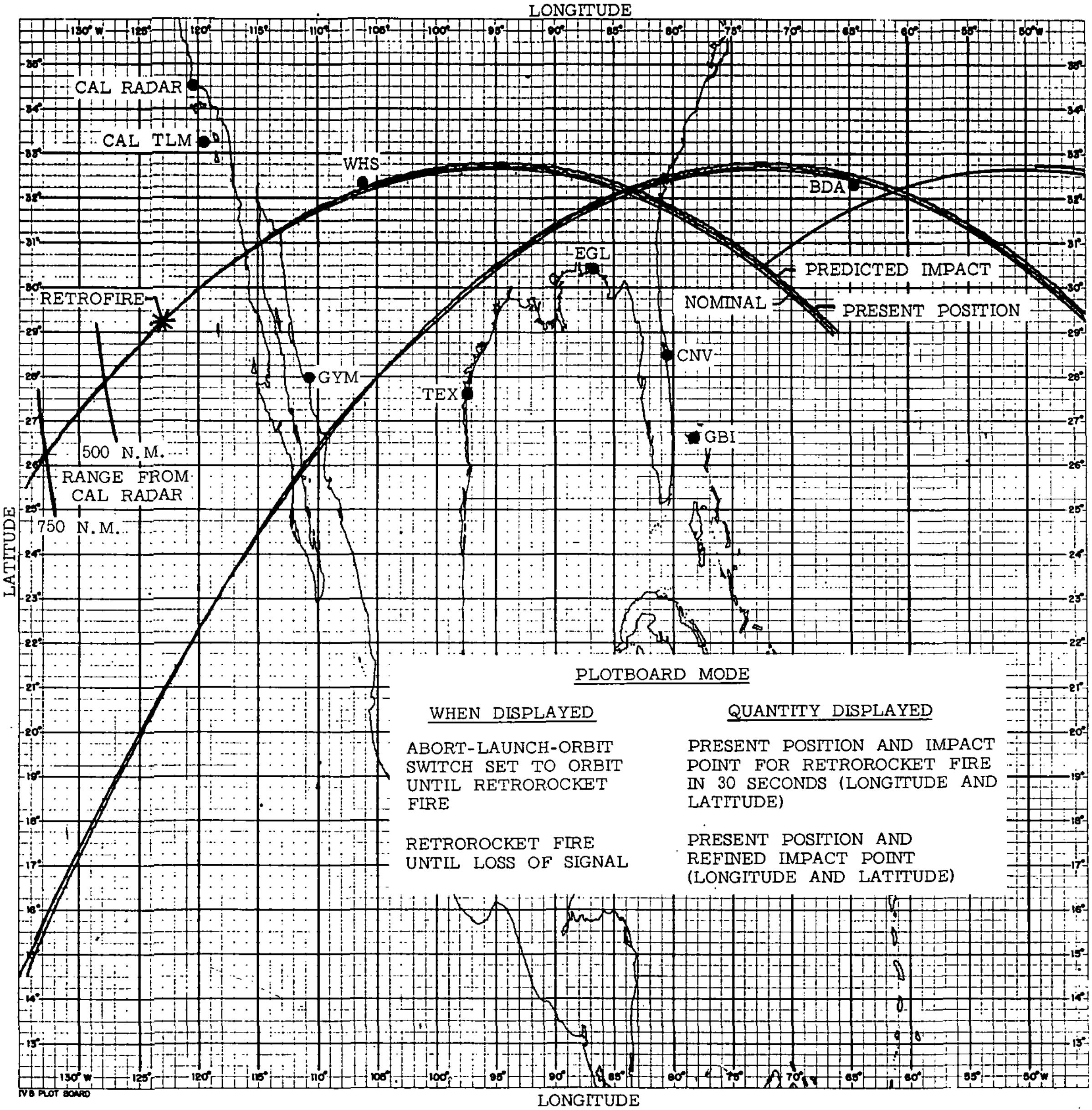
(b) Plotboard IIB. Semi-major axis deviation and capsule altitude versus elapsed time.

Figure 21. - Continued.



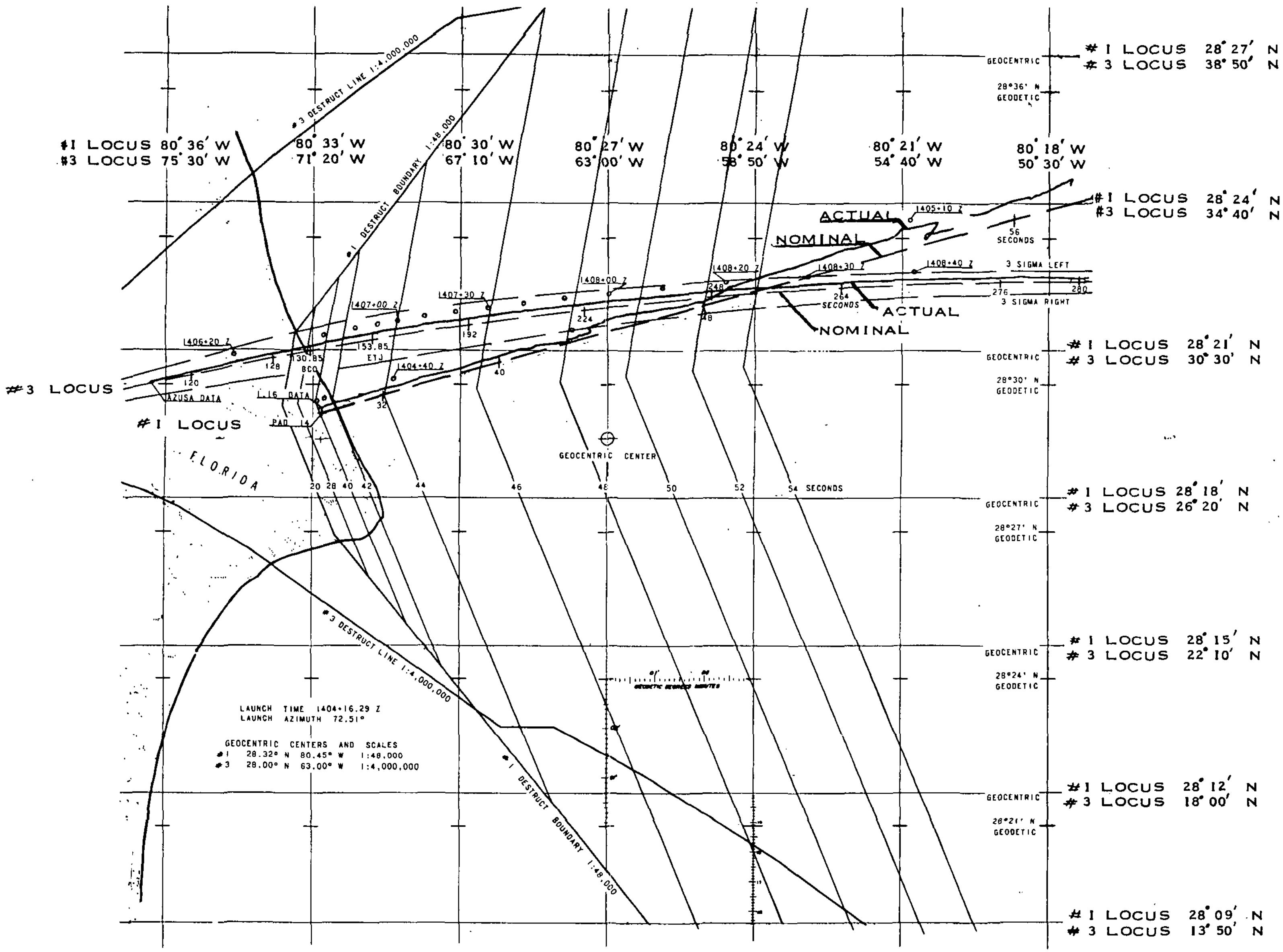
(c) Plotboard IIIB. Earth-fixed longitude of perigee and eccentricity versus elapsed time.

Figure 21. - Continued.



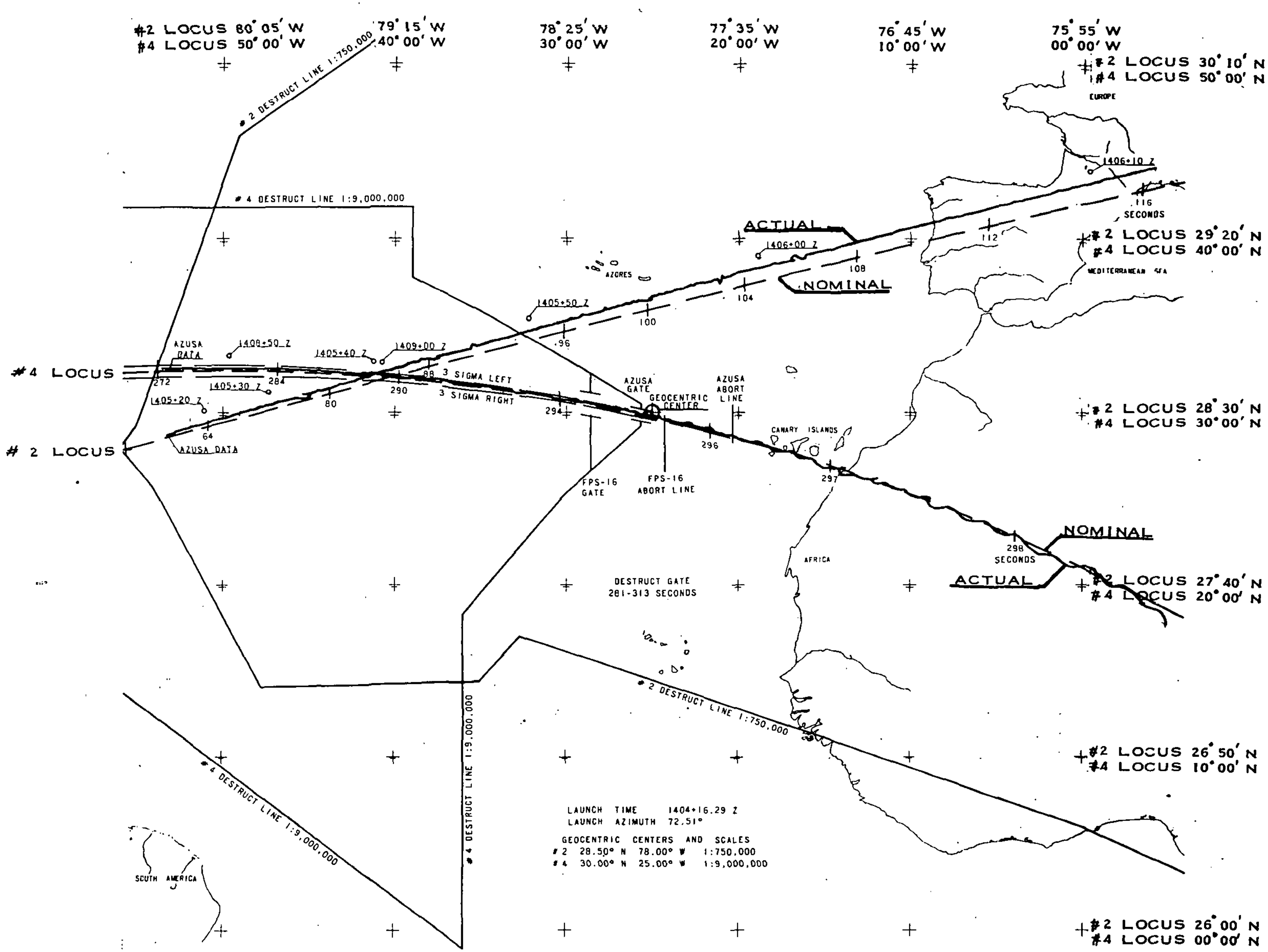
(d) Plotboard IV B. Present position and predicted impact point.

Figure 21. - Concluded.



(a) Latitude and longitude of predicted impact points shown as locus 1 and locus 3.

Figure 22. - Range Safety plotboards for MA-4 mission.



(b) Latitude and longitude of predicted impact points shown as locus 2 and locus 4.

Figure 22. - Continued.

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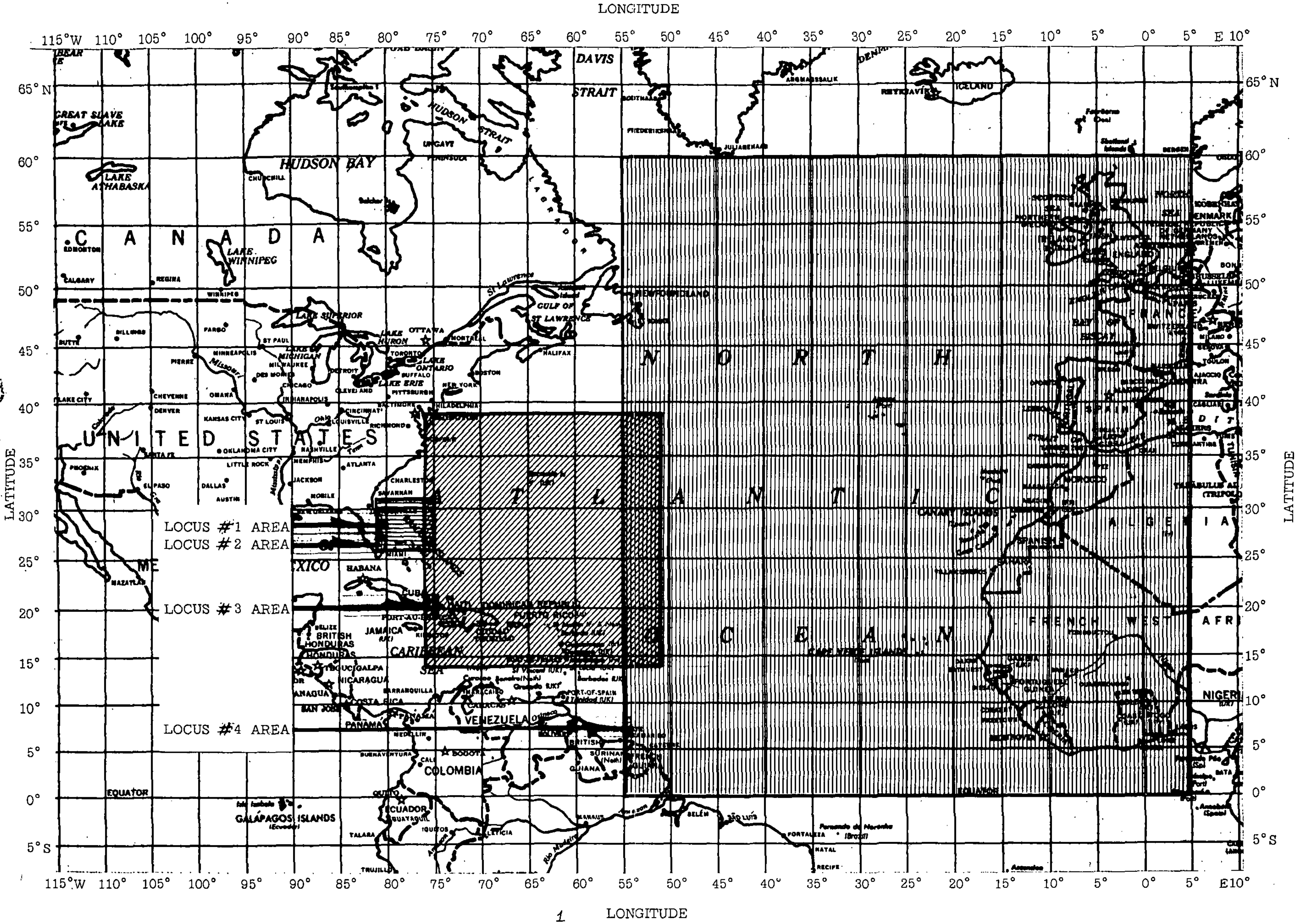
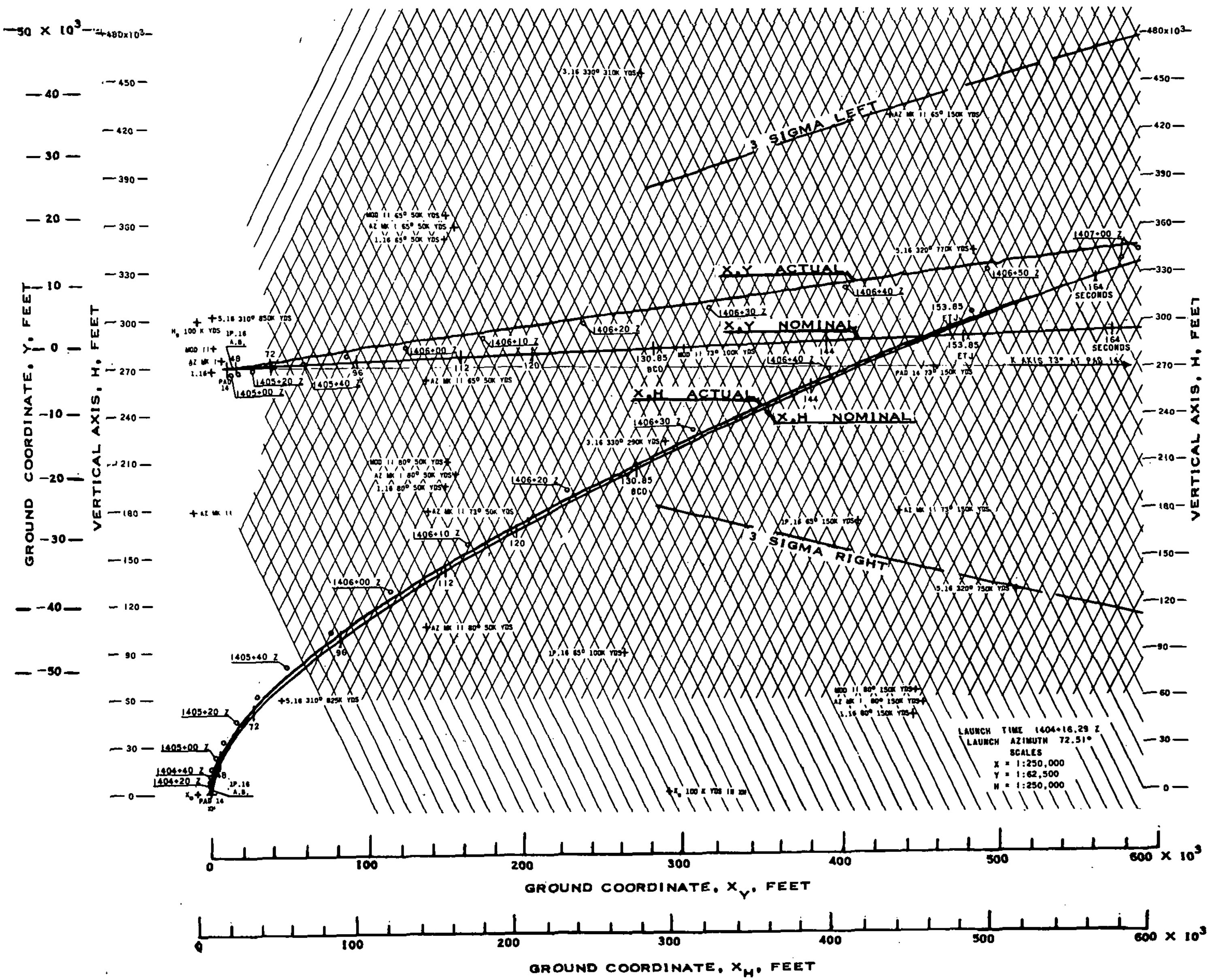


1

(c) Areas in which locii 1, 2, 3 and 4 are displayed (see figures 6a and 6b).

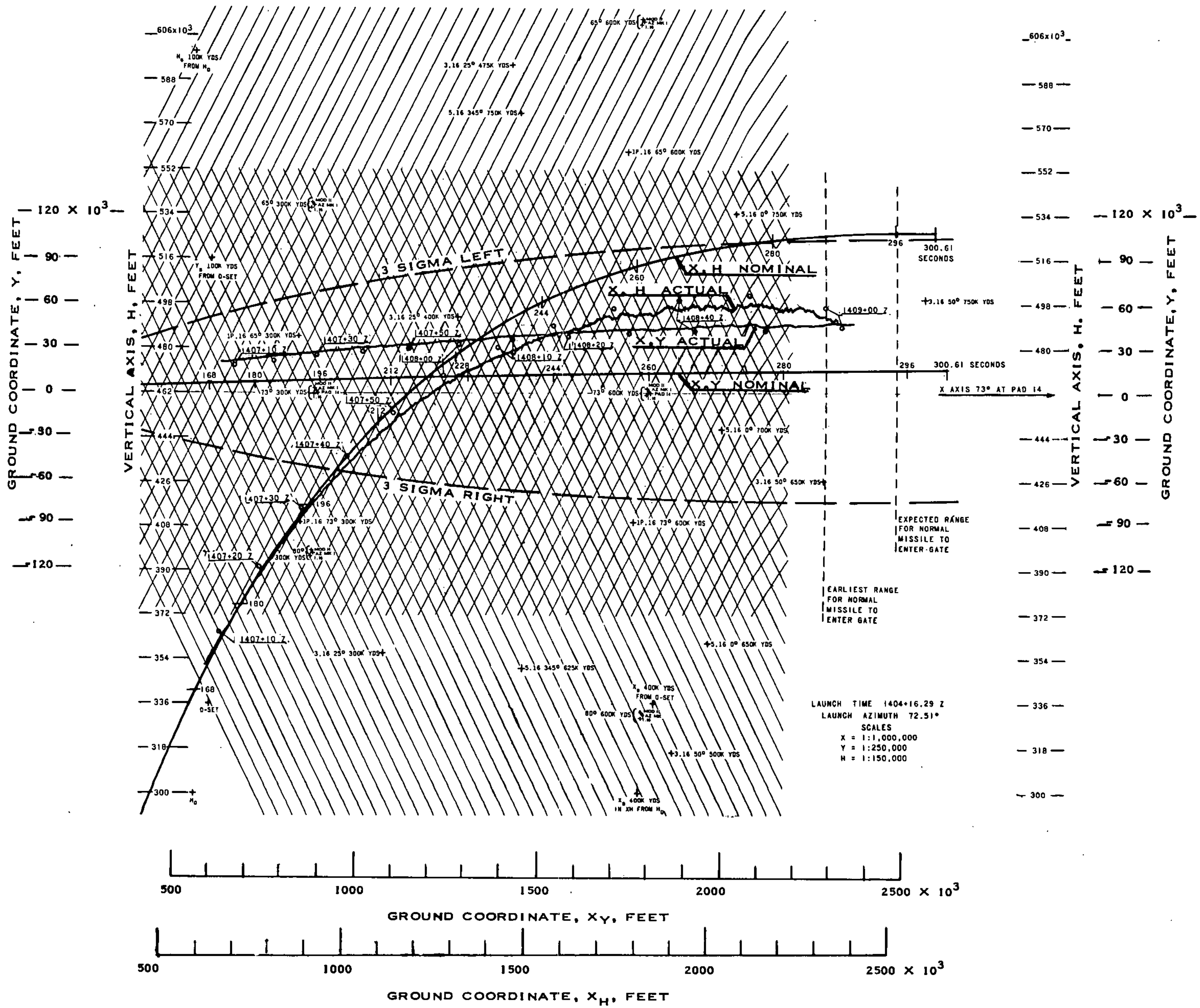
Figure 22. - Continued.



(d) X, Y and X, H trajectory plots from launch to 164 seconds.

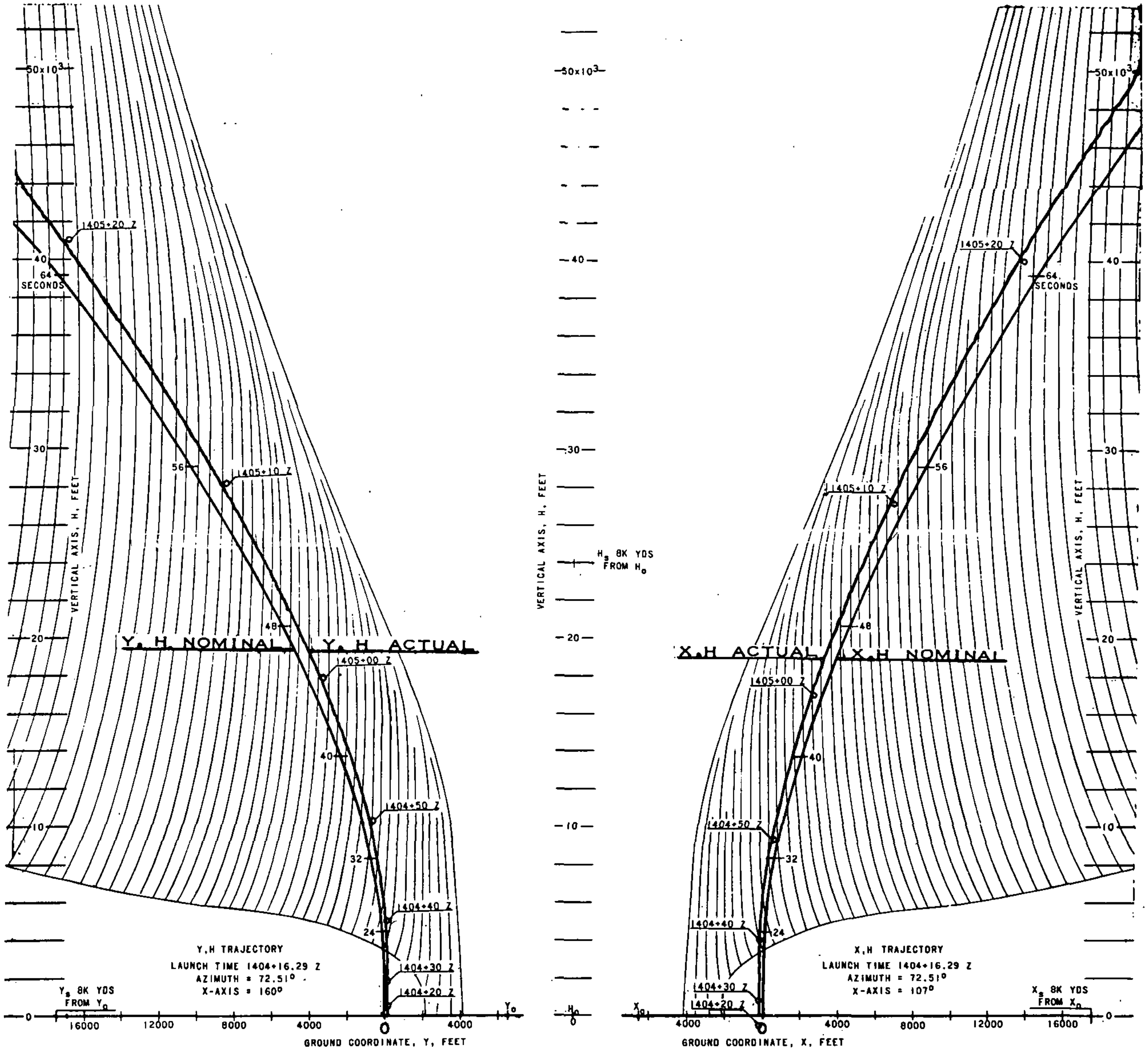
Figure 22.- Continued.

[redacted]



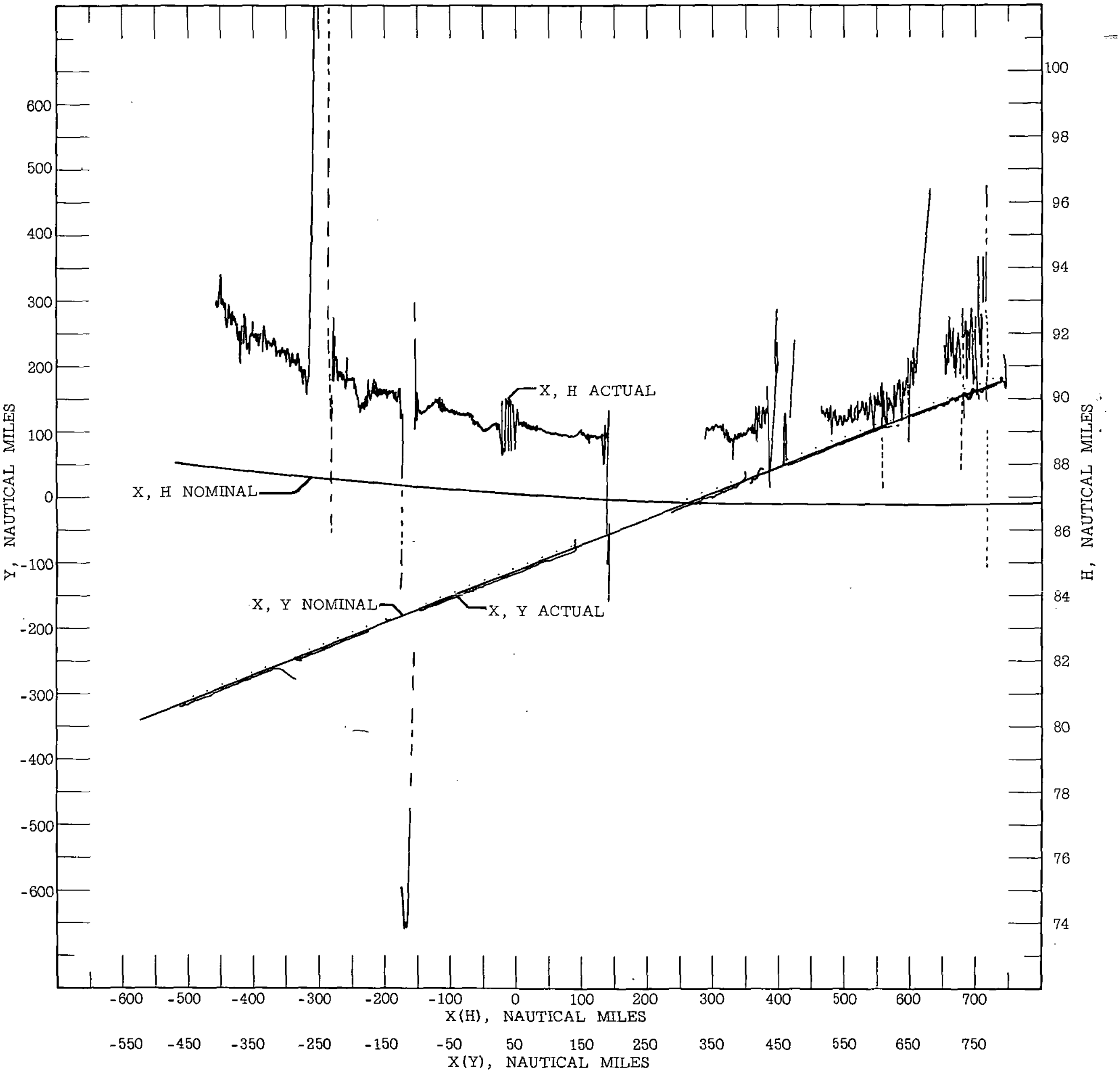
(e) X, Y and X, H trajectory plots from 164 seconds to insertion.

Figure 22. - Continued.



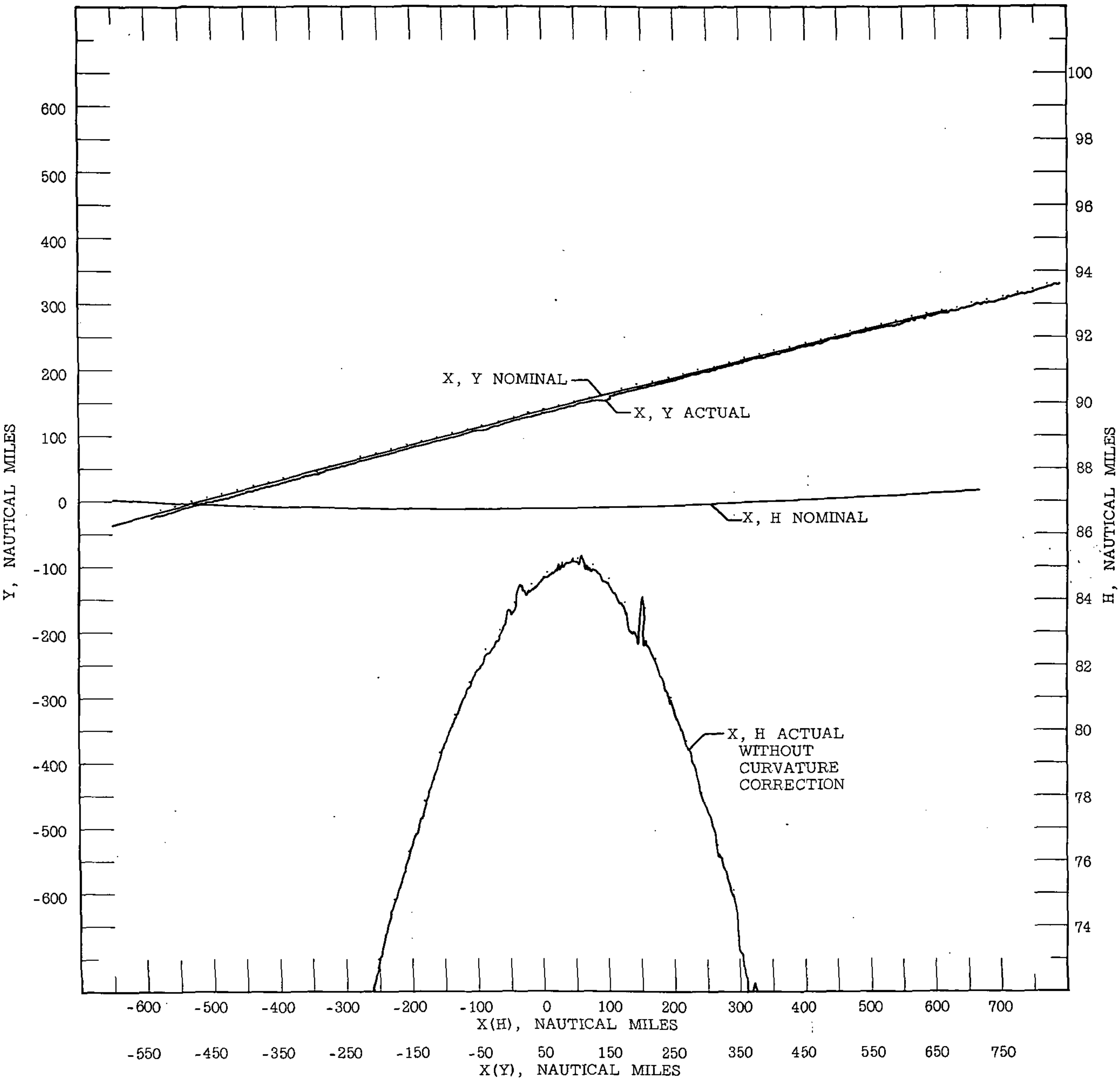
(f) X, H and Y, H vertical trajectory plots up to 50, 000 feet.

Figure 22. - Concluded



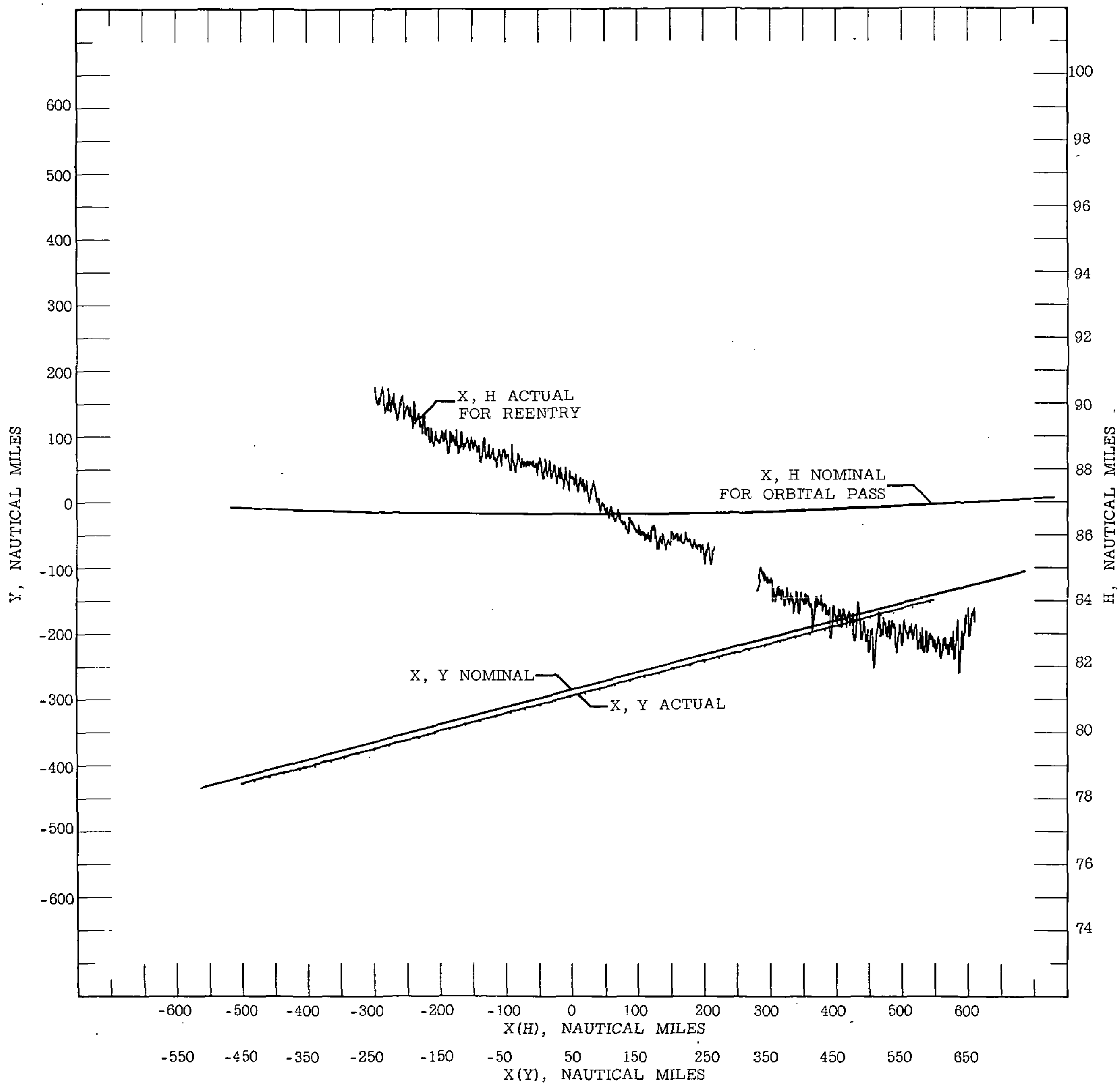
(a) Guaymas. First orbit, first pass.

Figure 23. - Remote site radar plotboard displays for MA-5.



(b) Texas. First orbit, first pass.

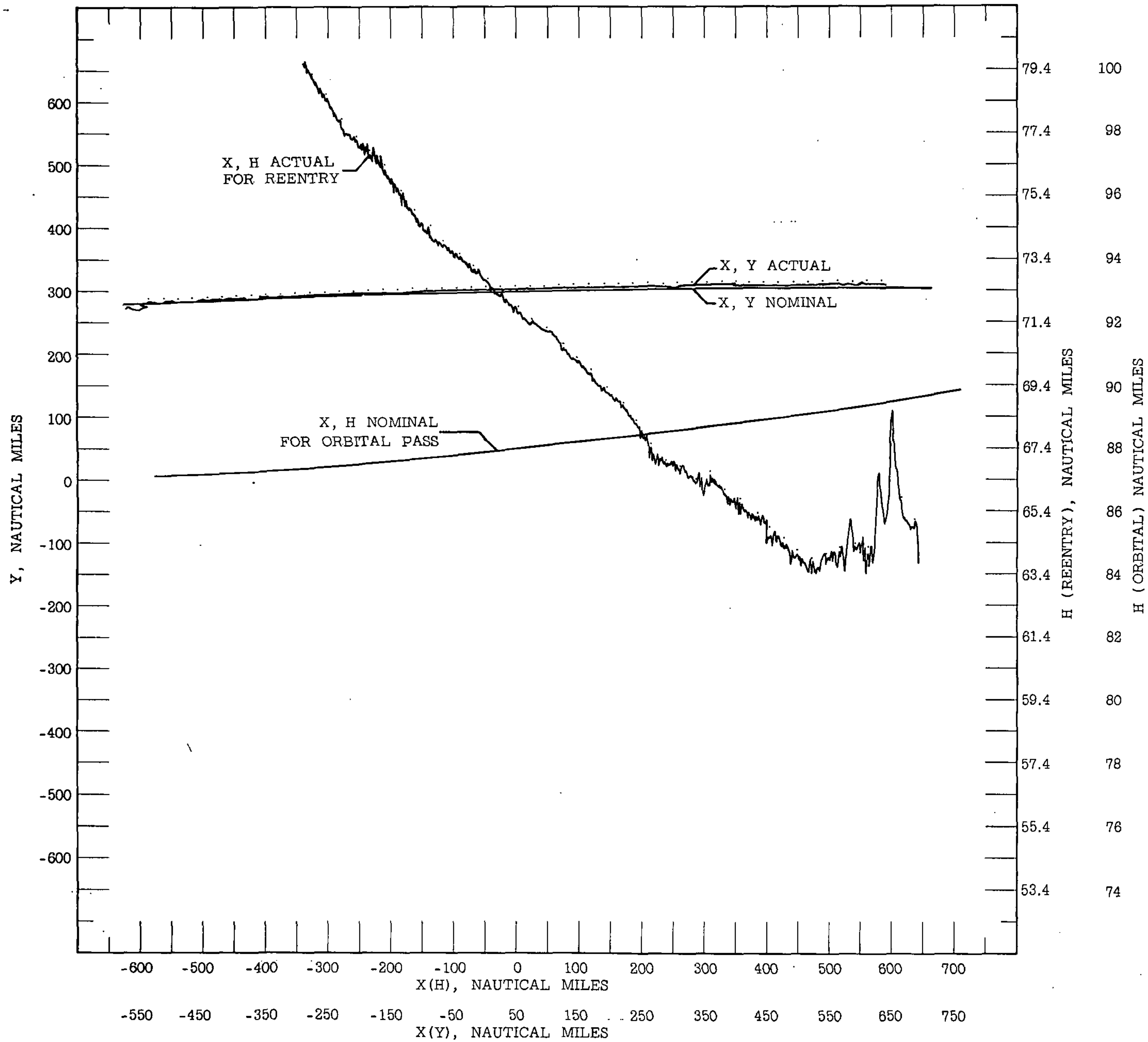
Figure 23. - Continued.



(c) California. Second orbit, reentry.

Figure 23. - Continued.

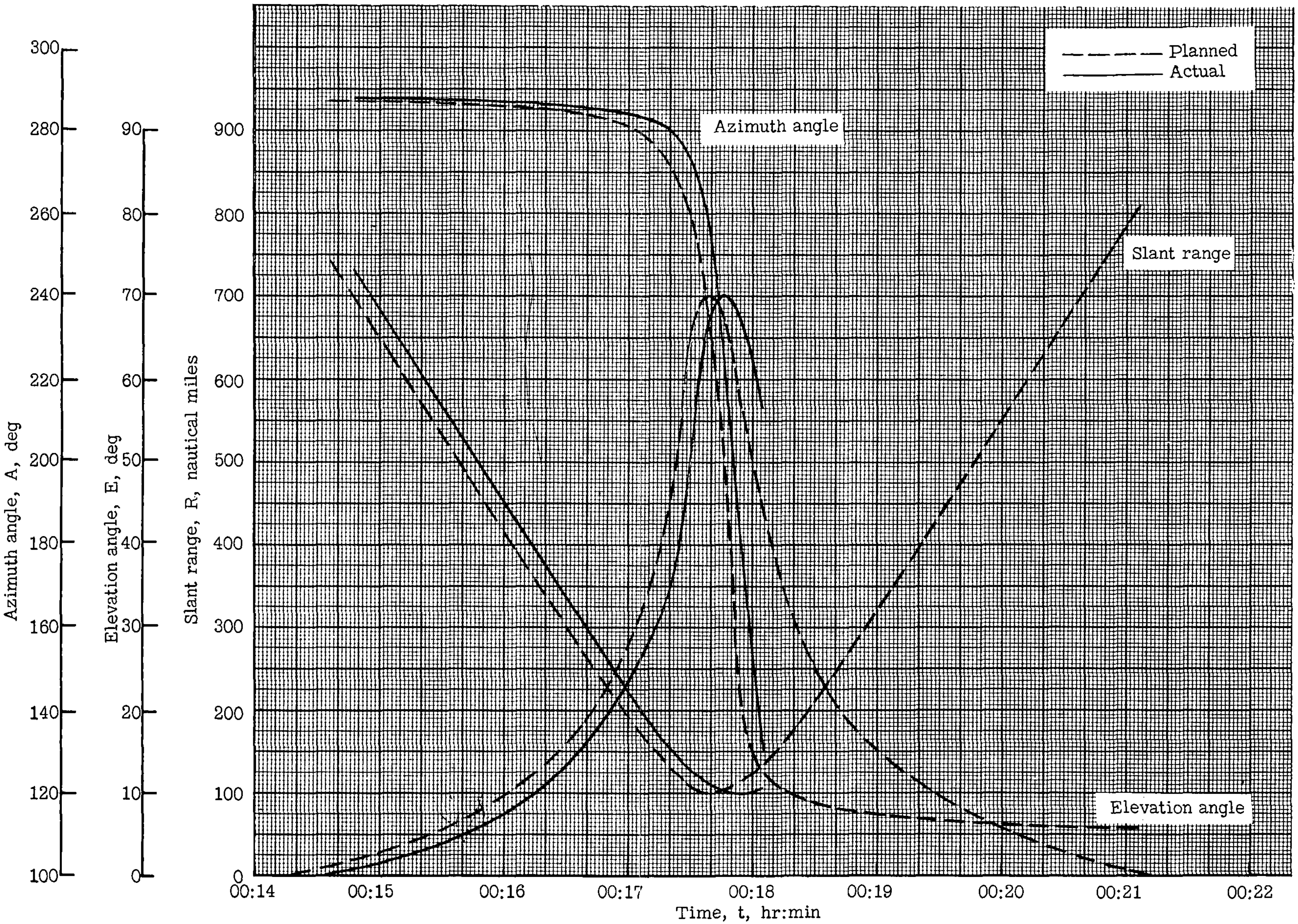
[redacted]



(d) Texas. Second orbit, reentry.

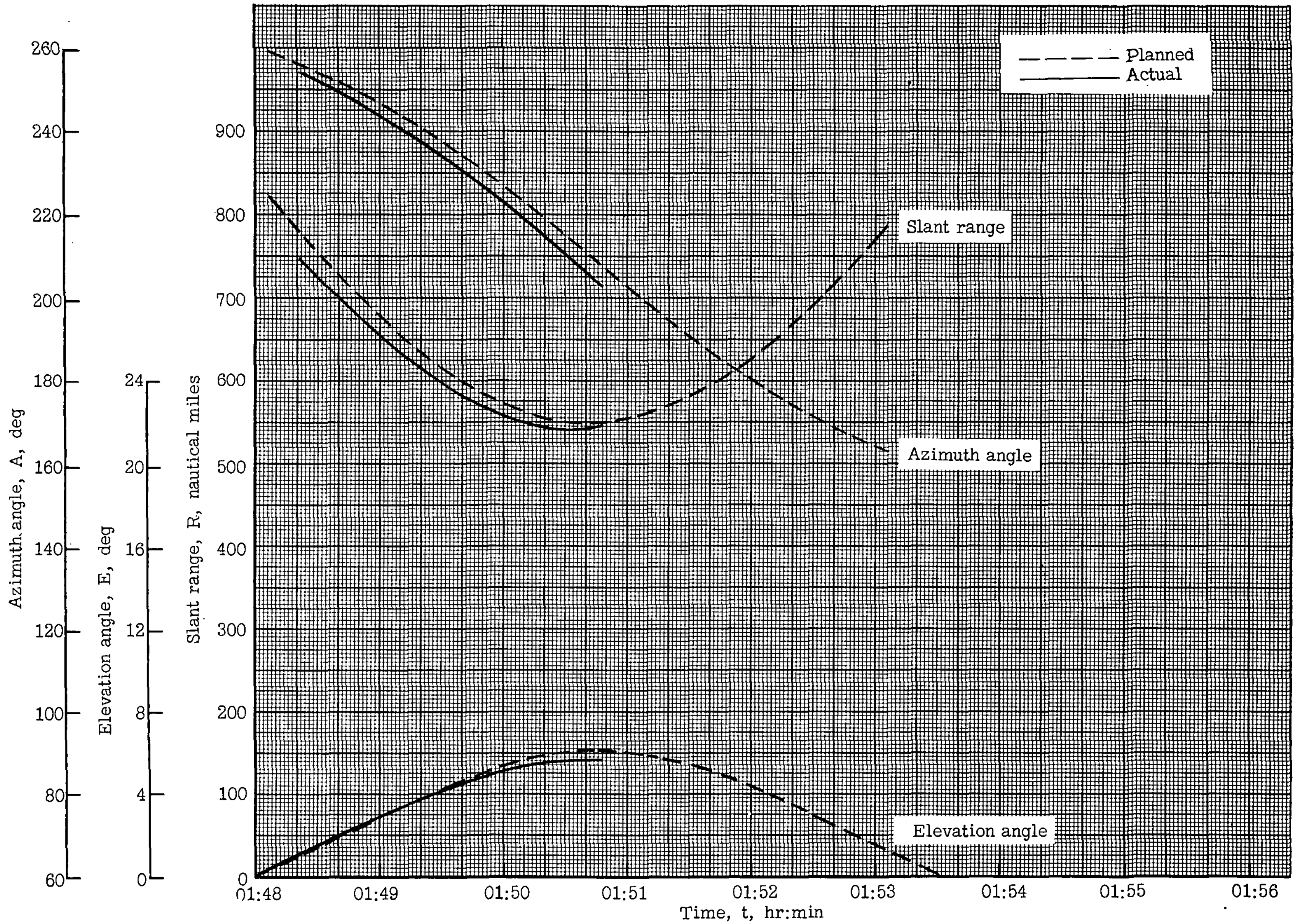
Figure 23. - Concluded.

[redacted]



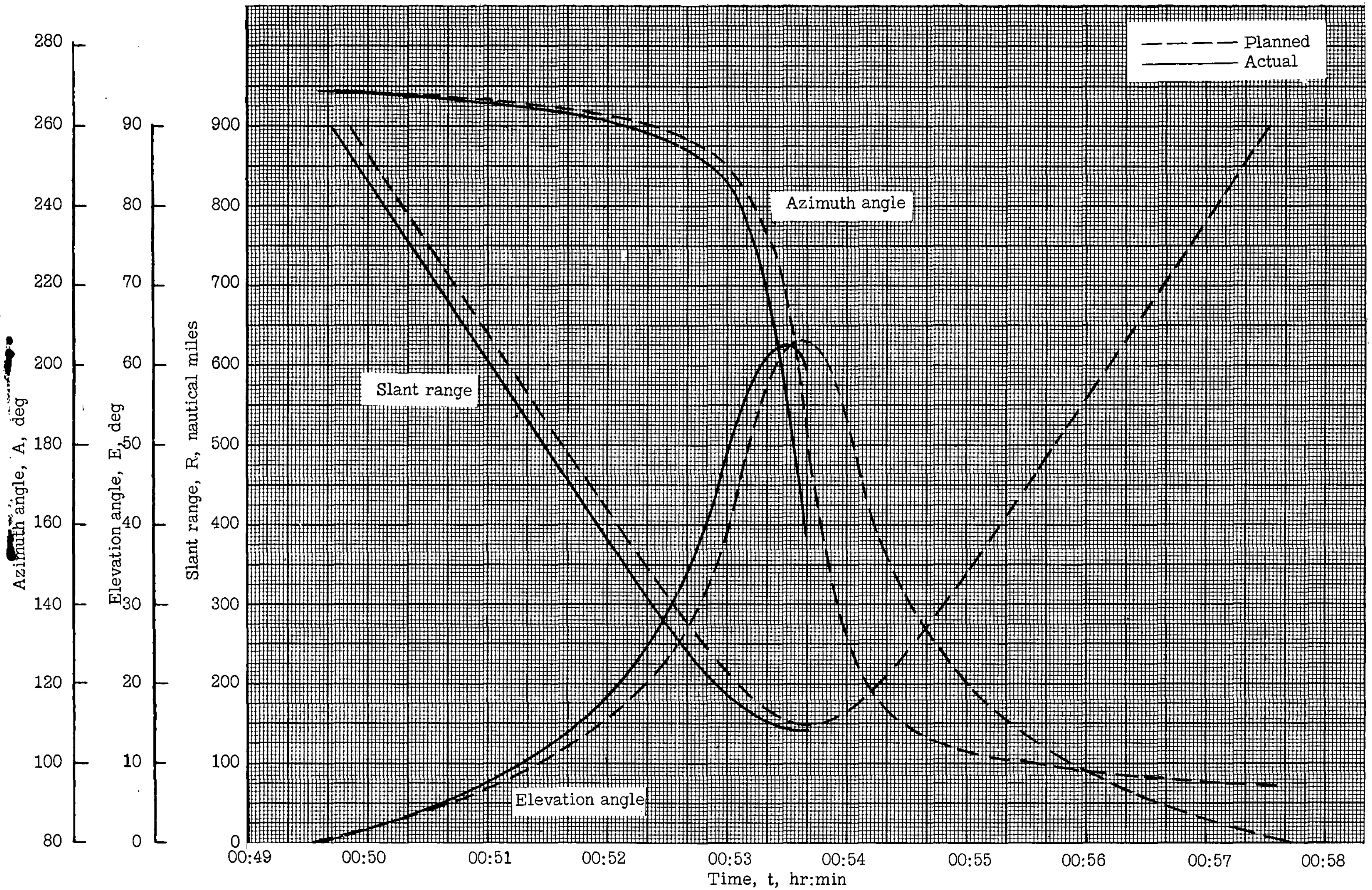
(a) Canary Islands, first orbit, first pass.

Figure 24.- Comparison of real time prediction and preflight prediction of range, azimuth and elevation radar sighting data for MA-5 mission.



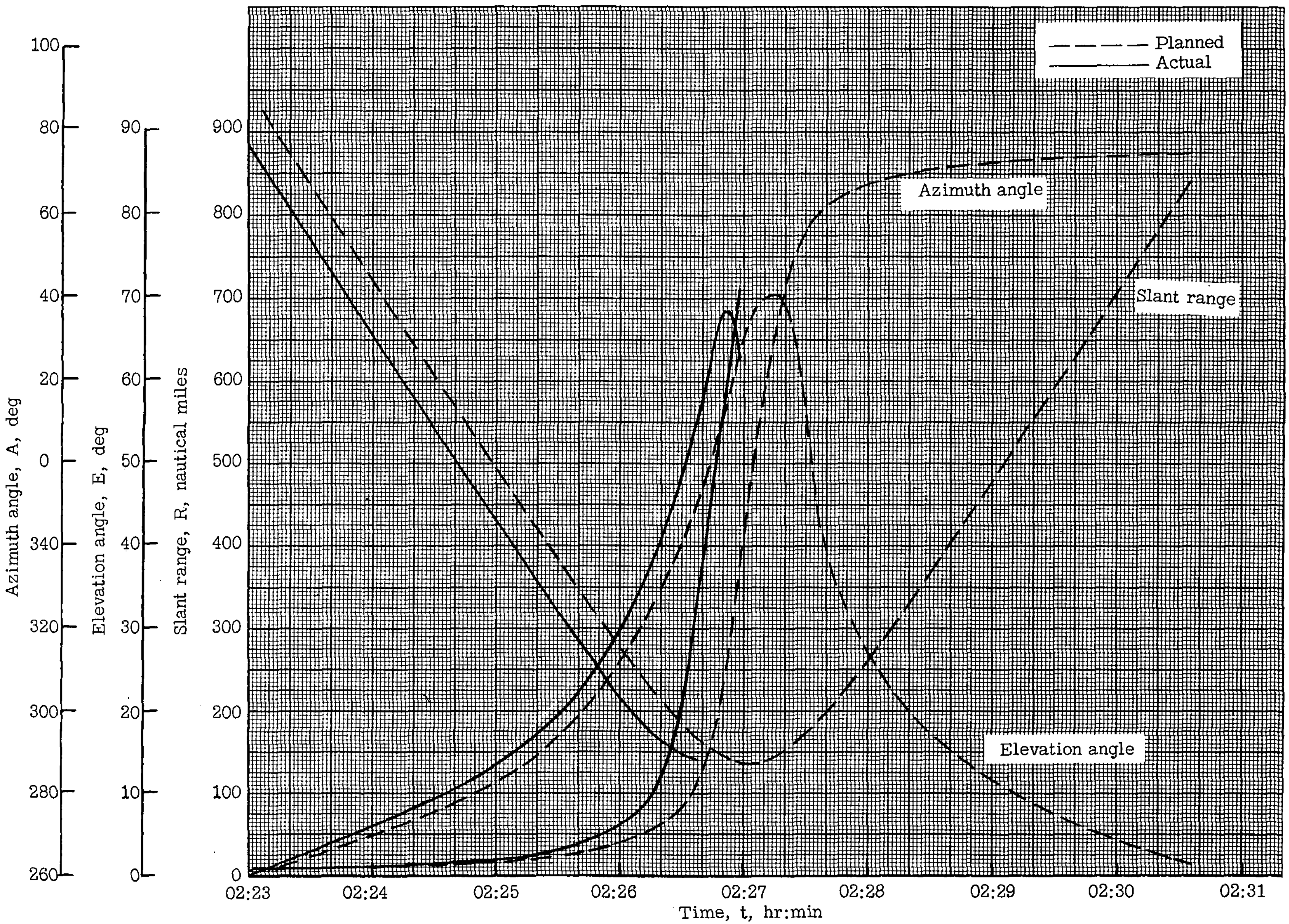
(b) Canary Islands, second orbit, second pass.

Figure 24. - Continued.



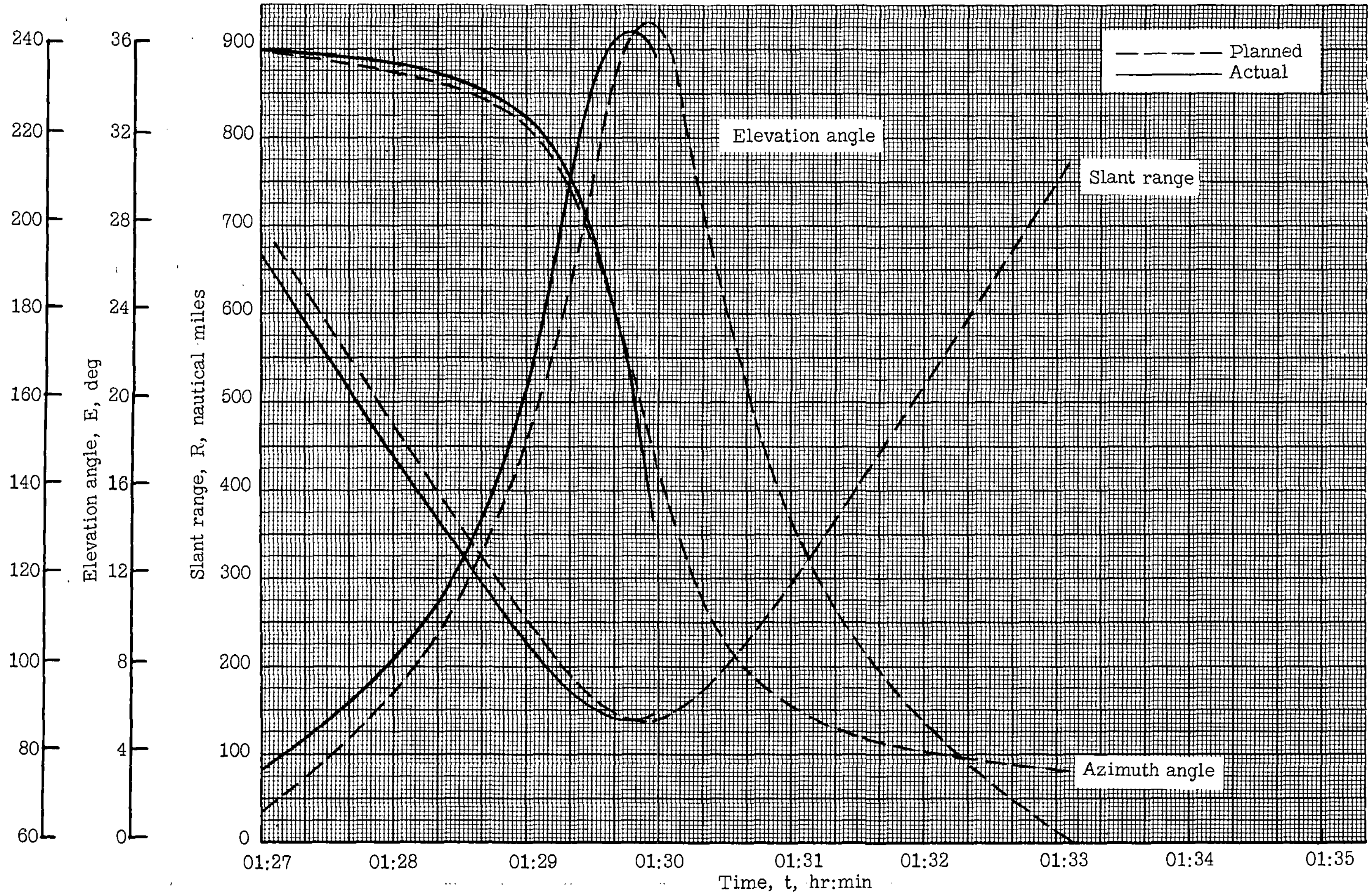
(c) Muchea, first orbit, first pass.

Figure 24. - Continued.



(d) Muchea, second orbit, second pass.

Figure 24. - Continued.



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(e) Guaymas, first orbit, first pass.

Figure 24. - Continued.

[redacted]

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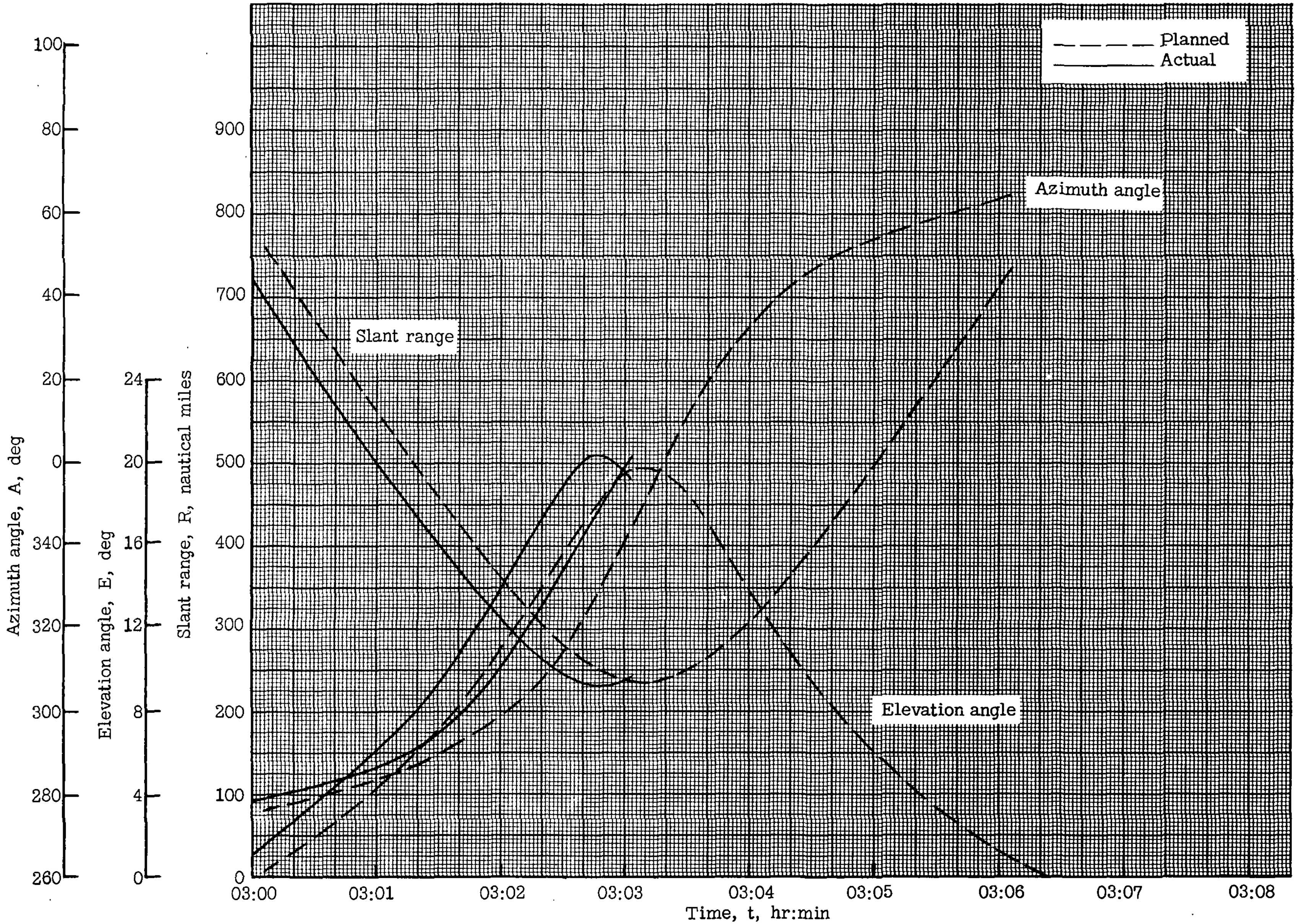
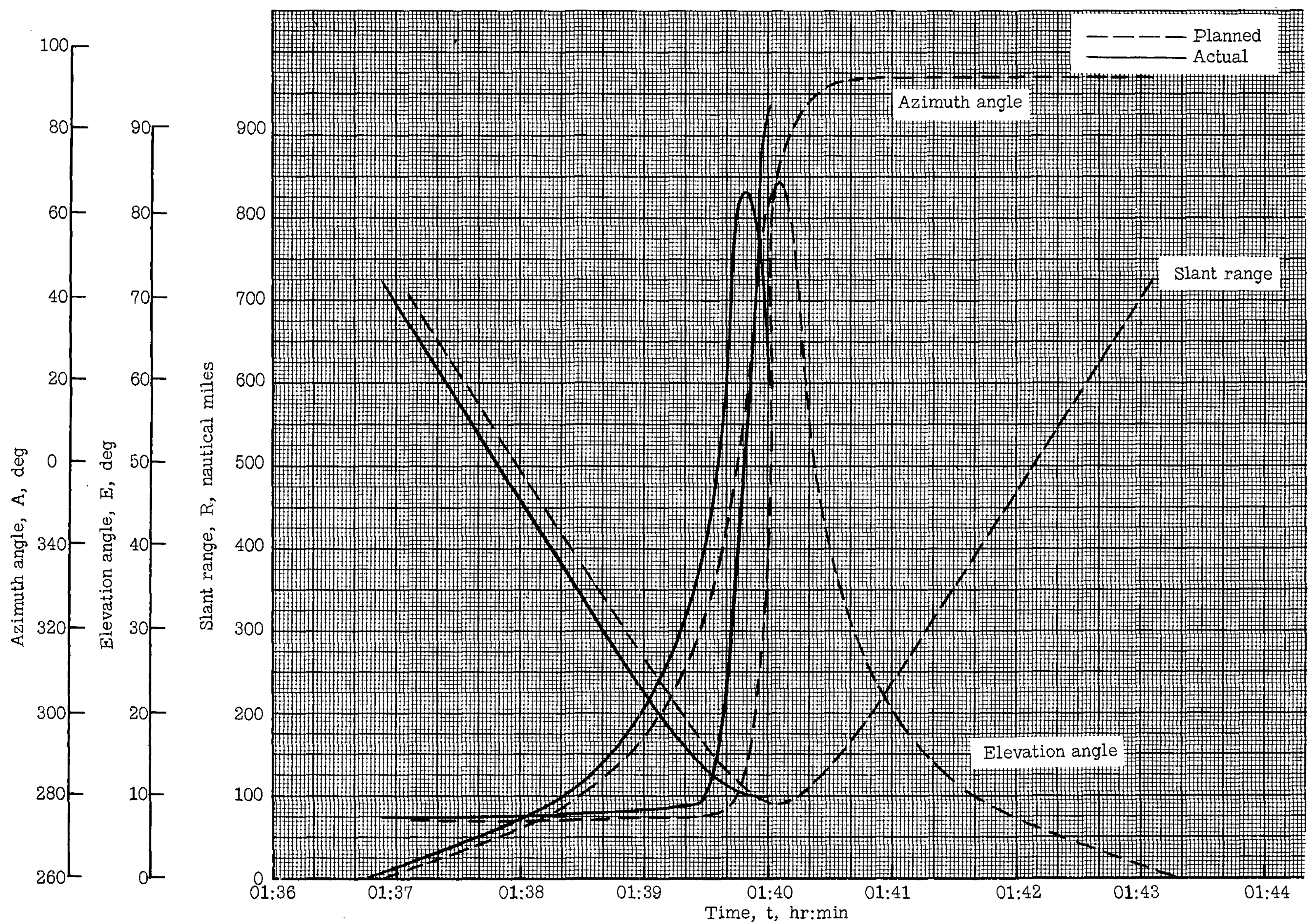


(f) Guaymas, second orbit, second pass.

Figure 24. - Continued.

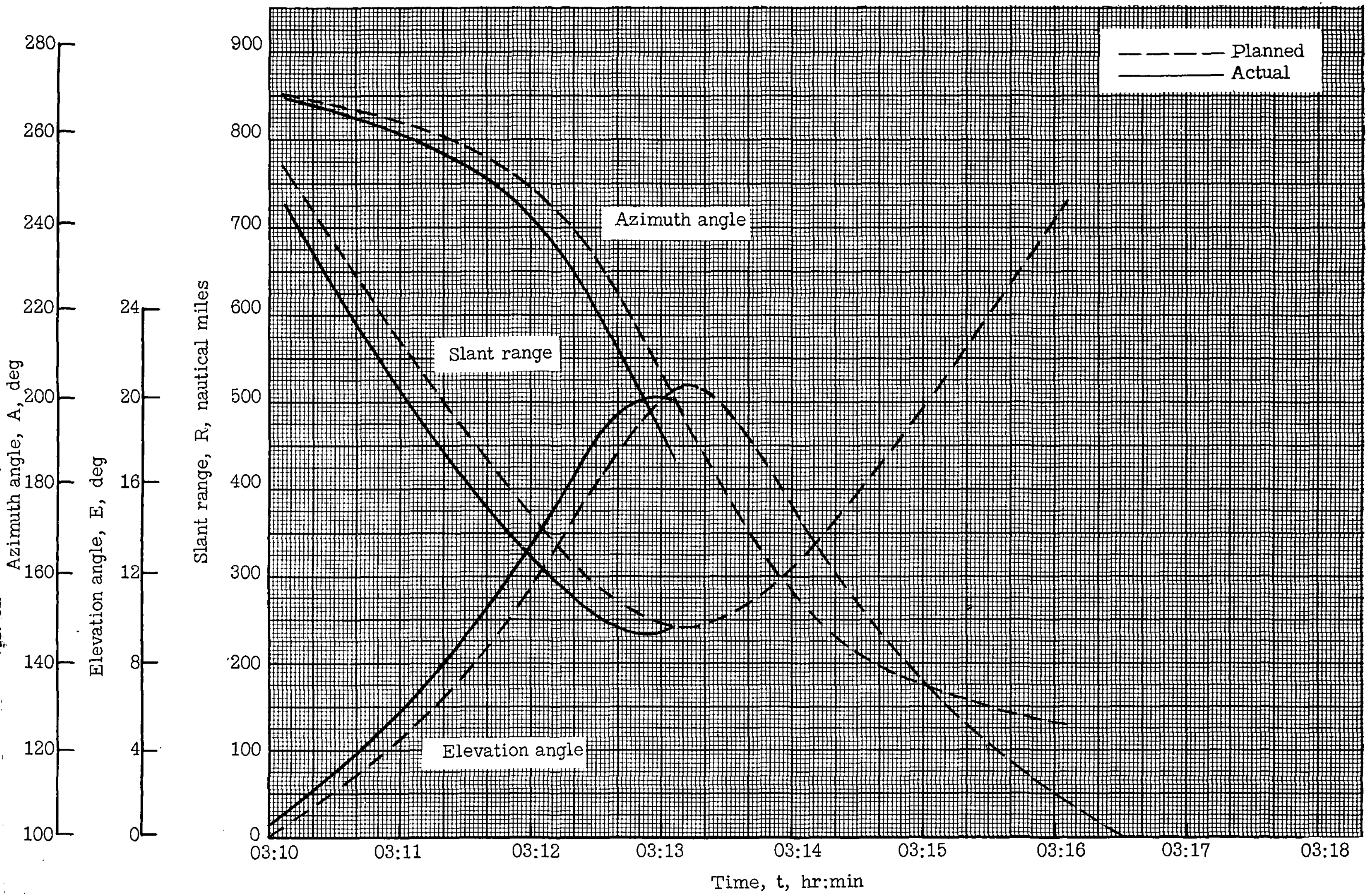
[redacted]



(g) Bermuda, second orbit, second pass.

Figure 24. - Continued.

[redacted]



(h) Bermuda, third orbit, third pass.

Figure 24. - Concluded.

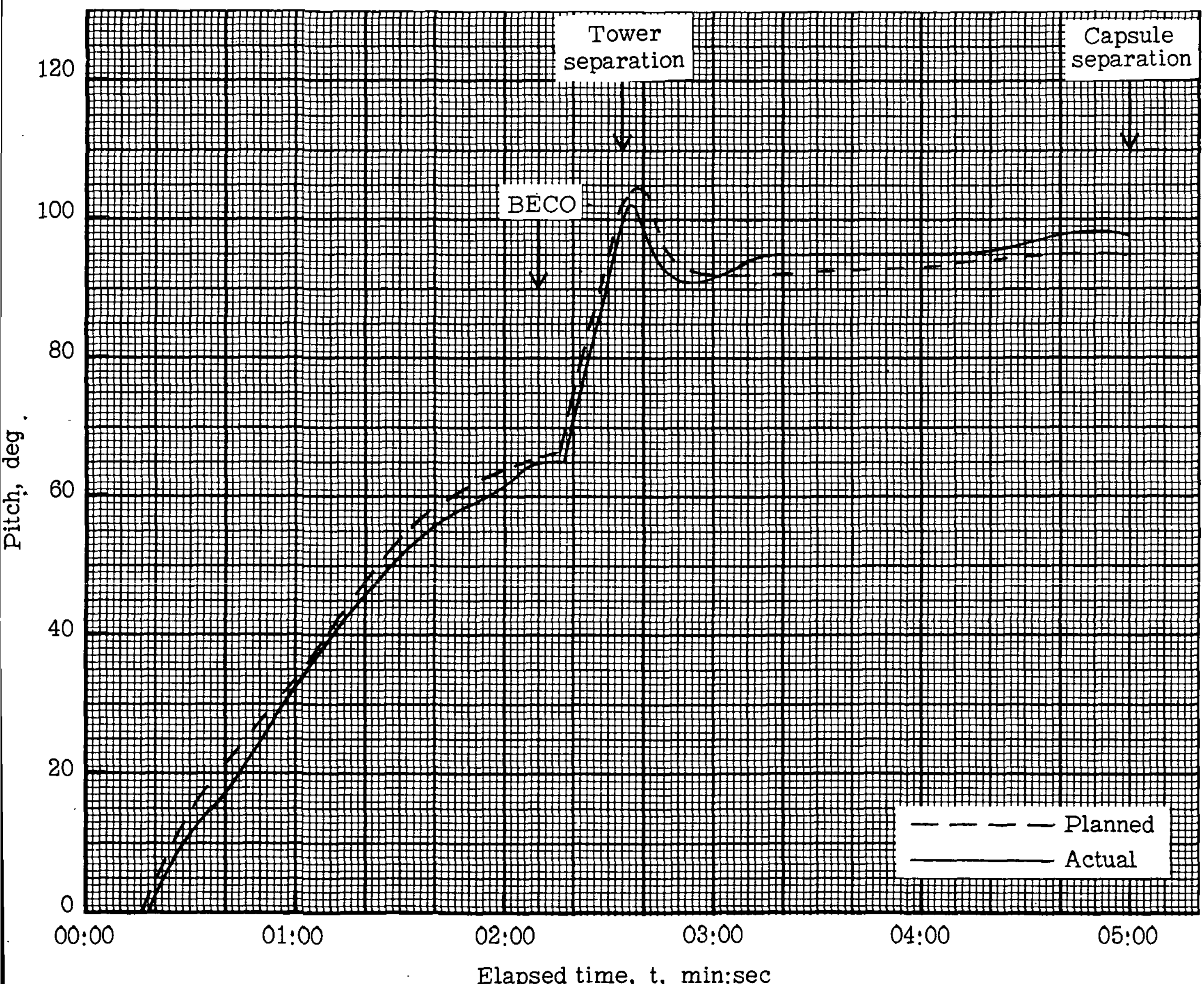
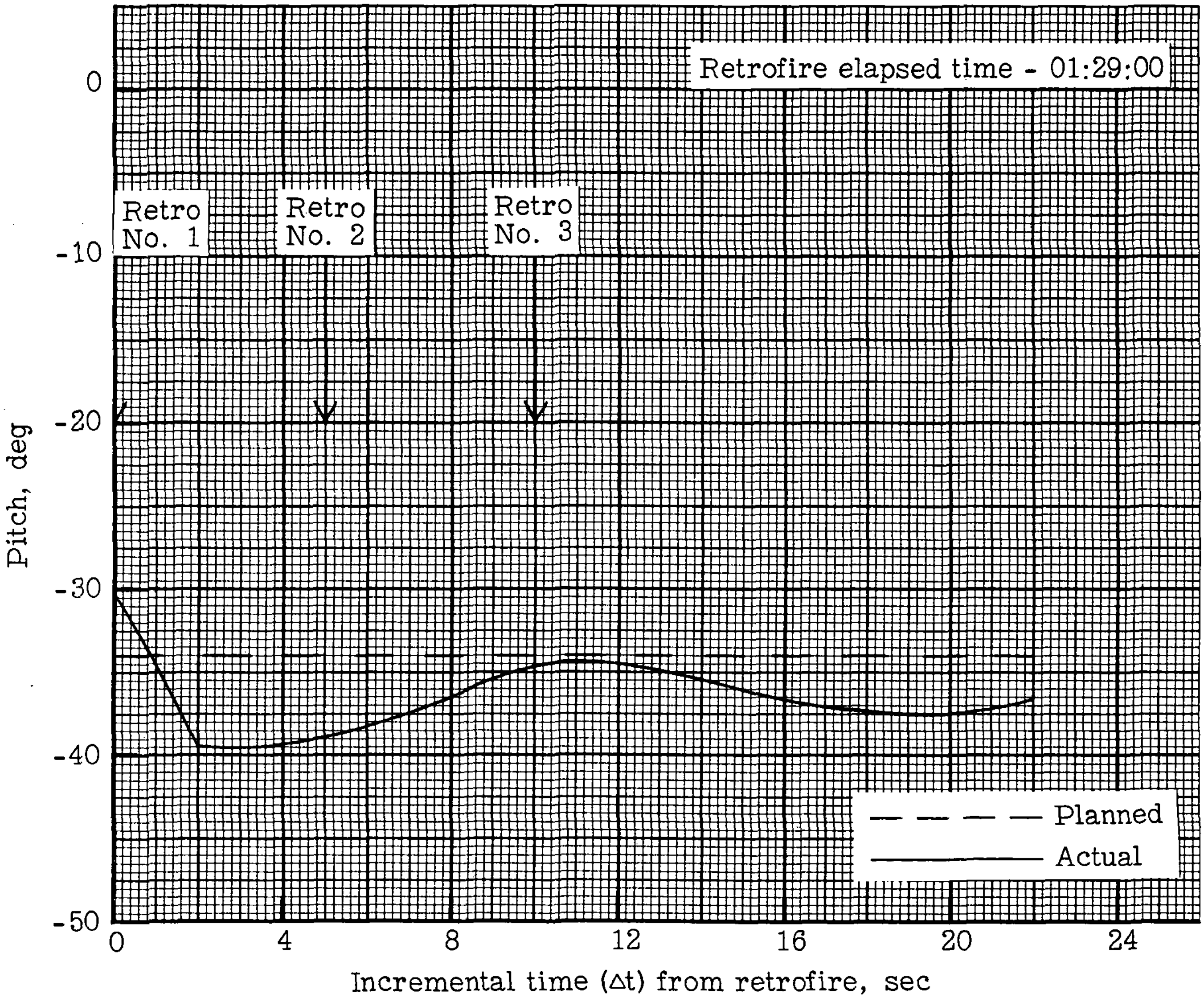
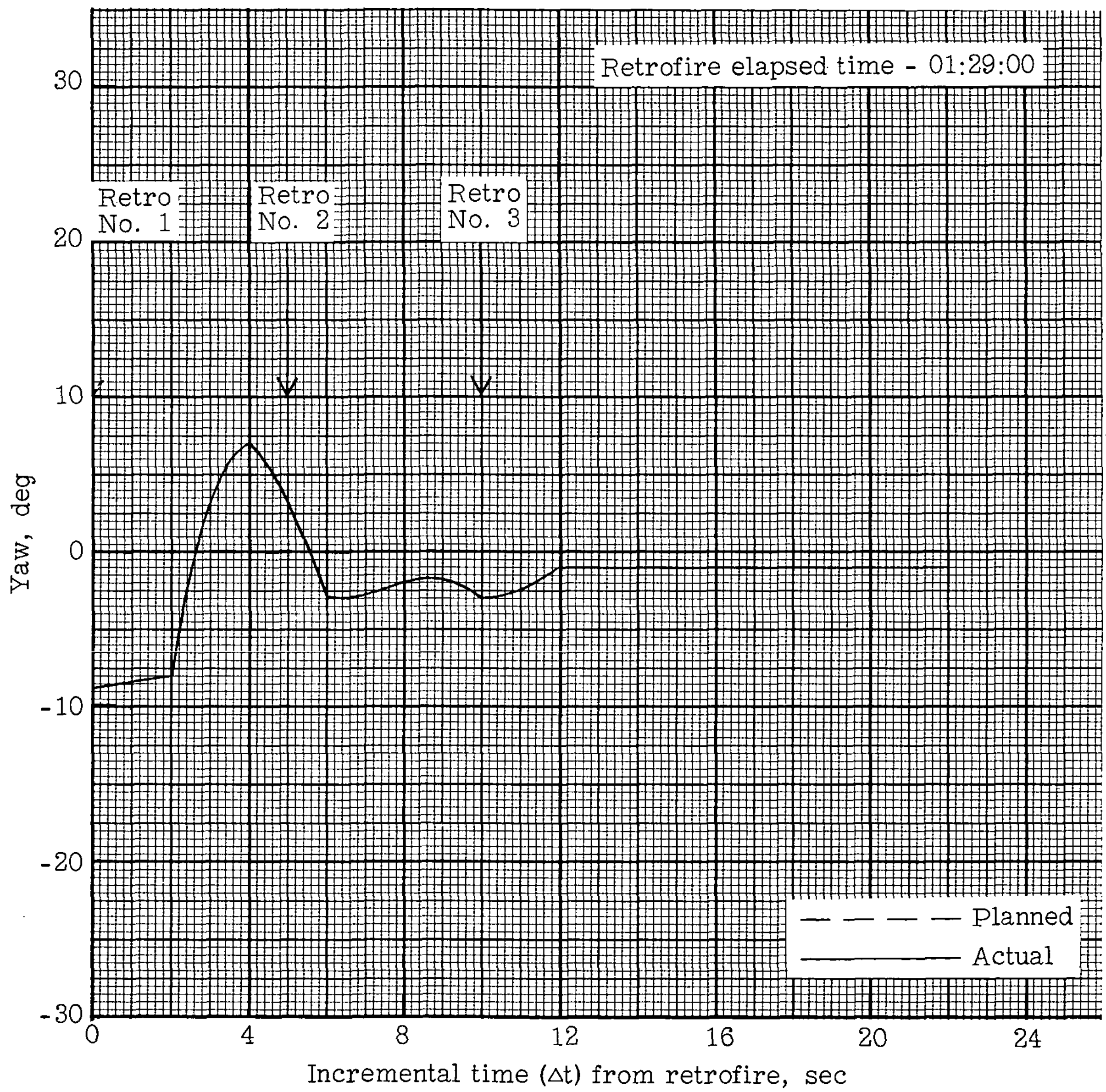


Figure 25. - Time history of pitch attitude during launch phase of the MA-5 mission compared with the nominal.



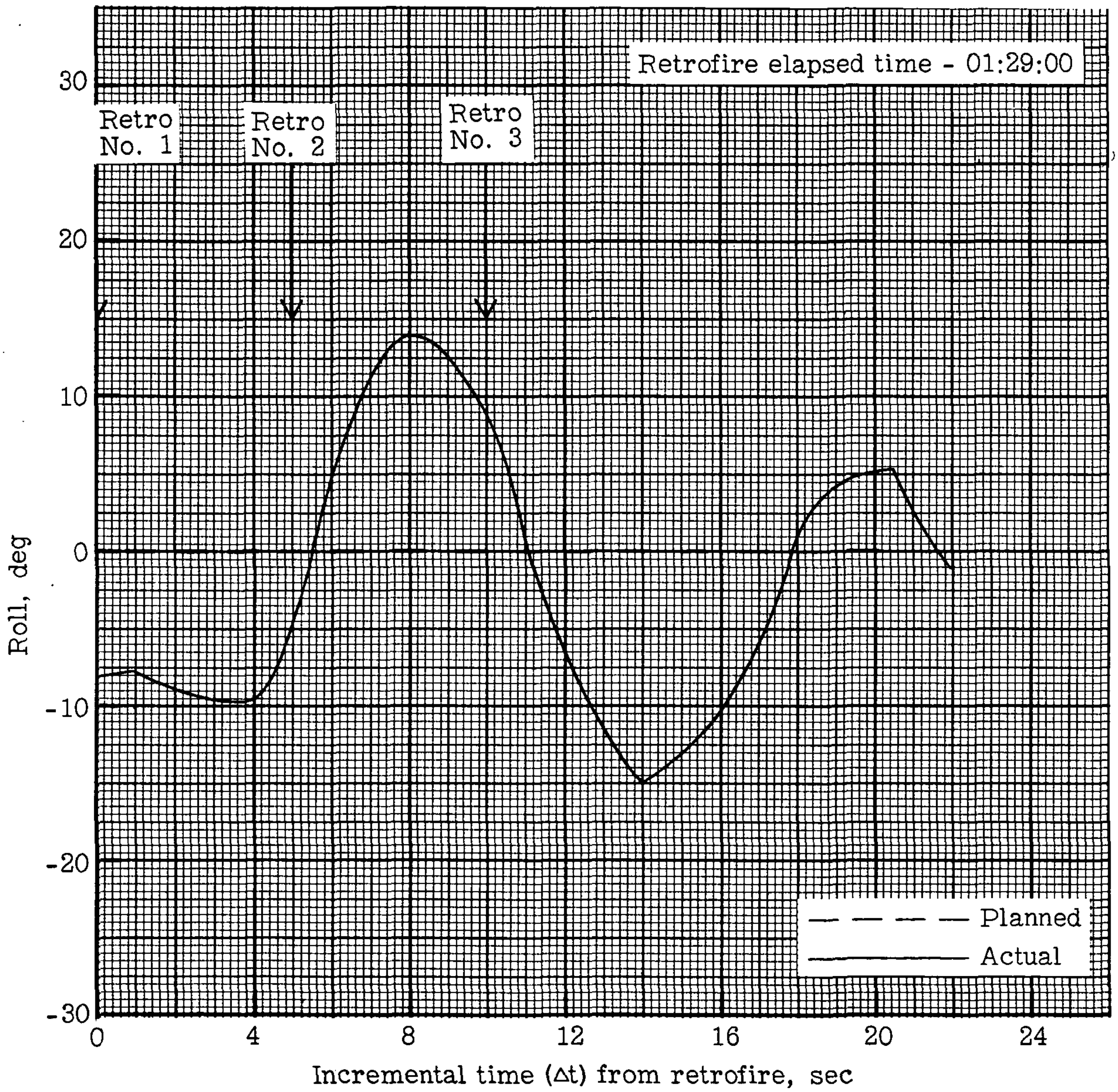
(a) Pitch angular attitude.

Figure 26. - Time history of capsule attitude during retrofire for the MA-4 mission compared with the nominal.



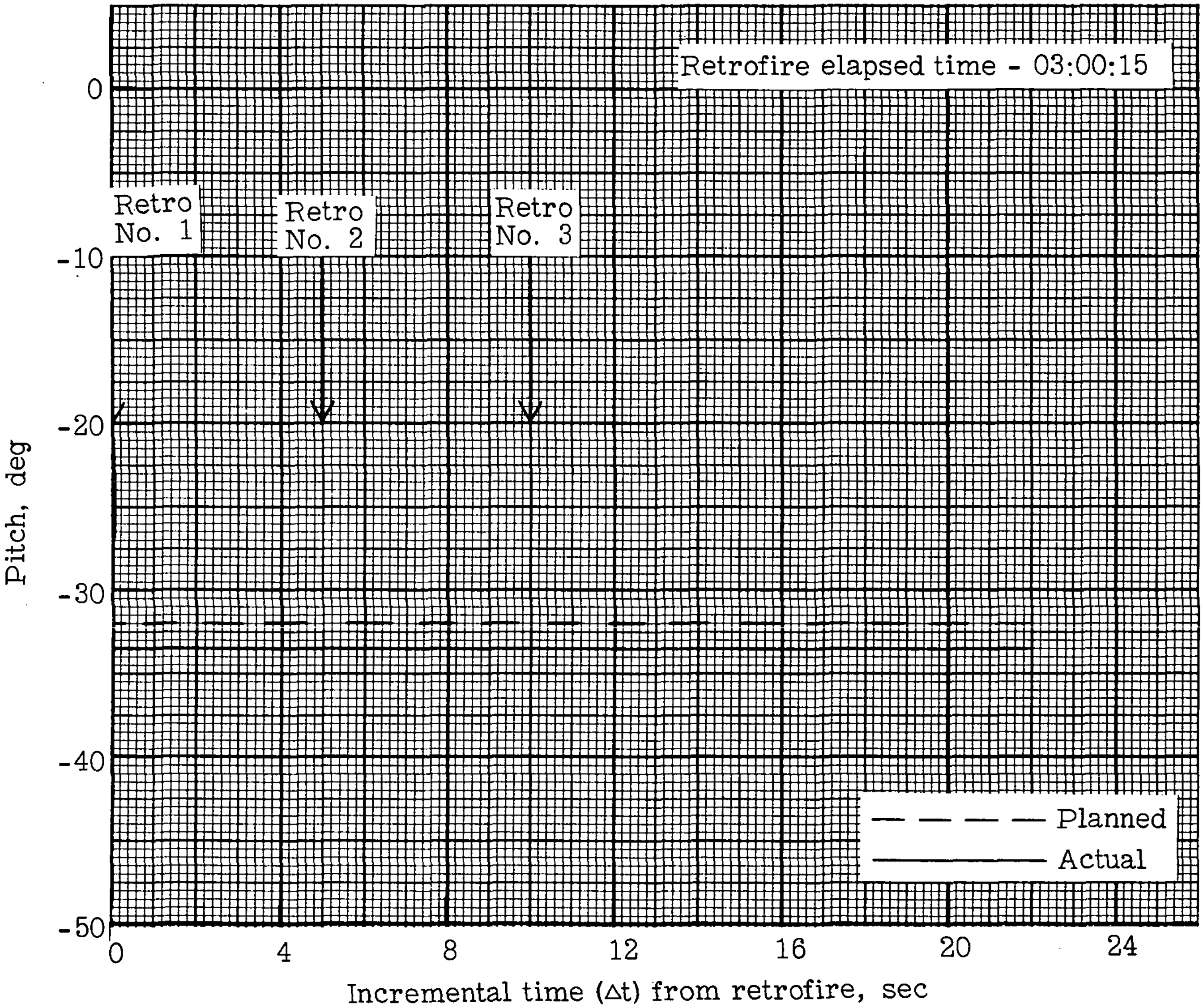
(b) Yaw angular attitude.

Figure 26 - Continued.



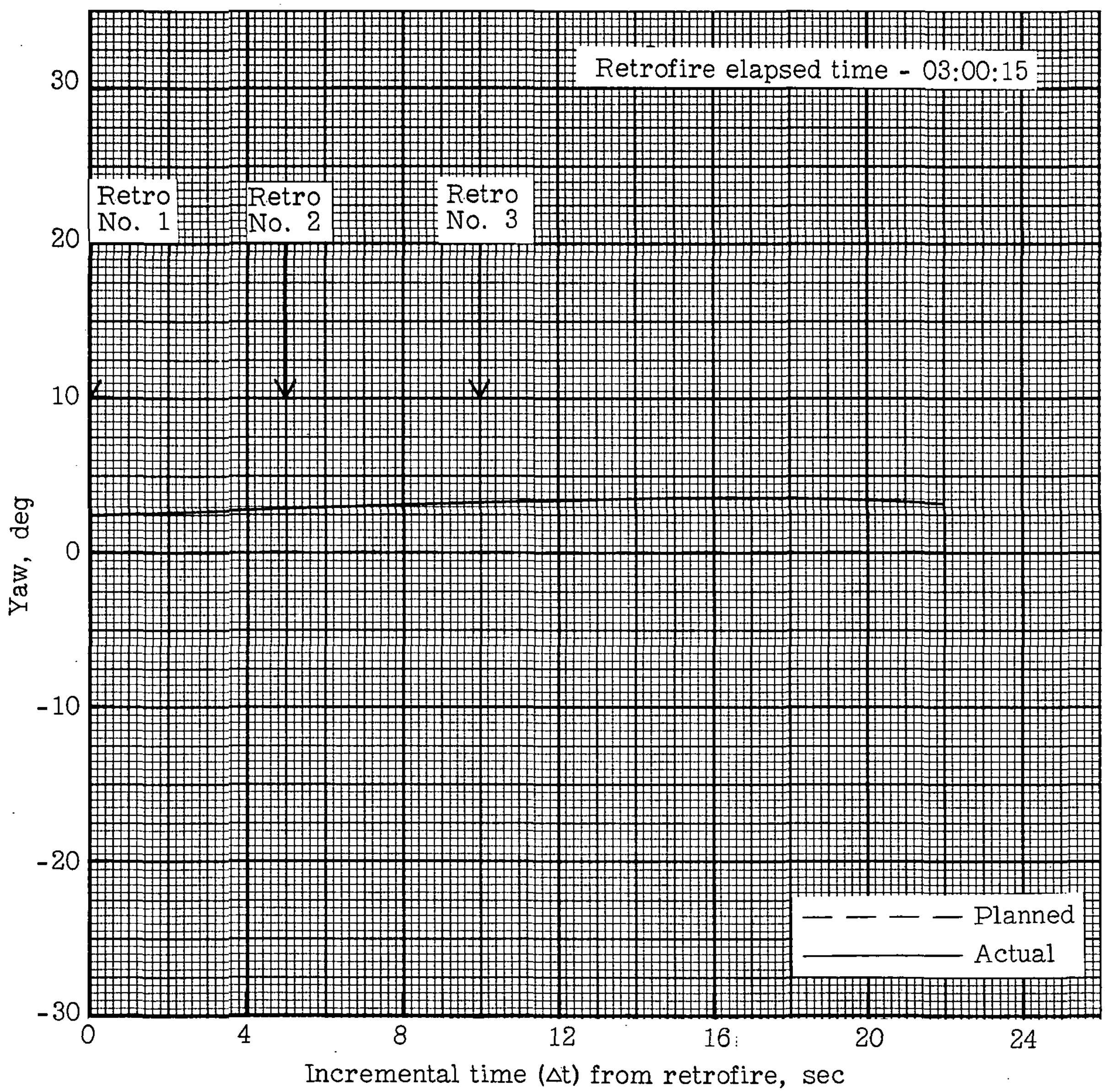
(c) Roll angular attitude.

Figure 26. - Concluded.



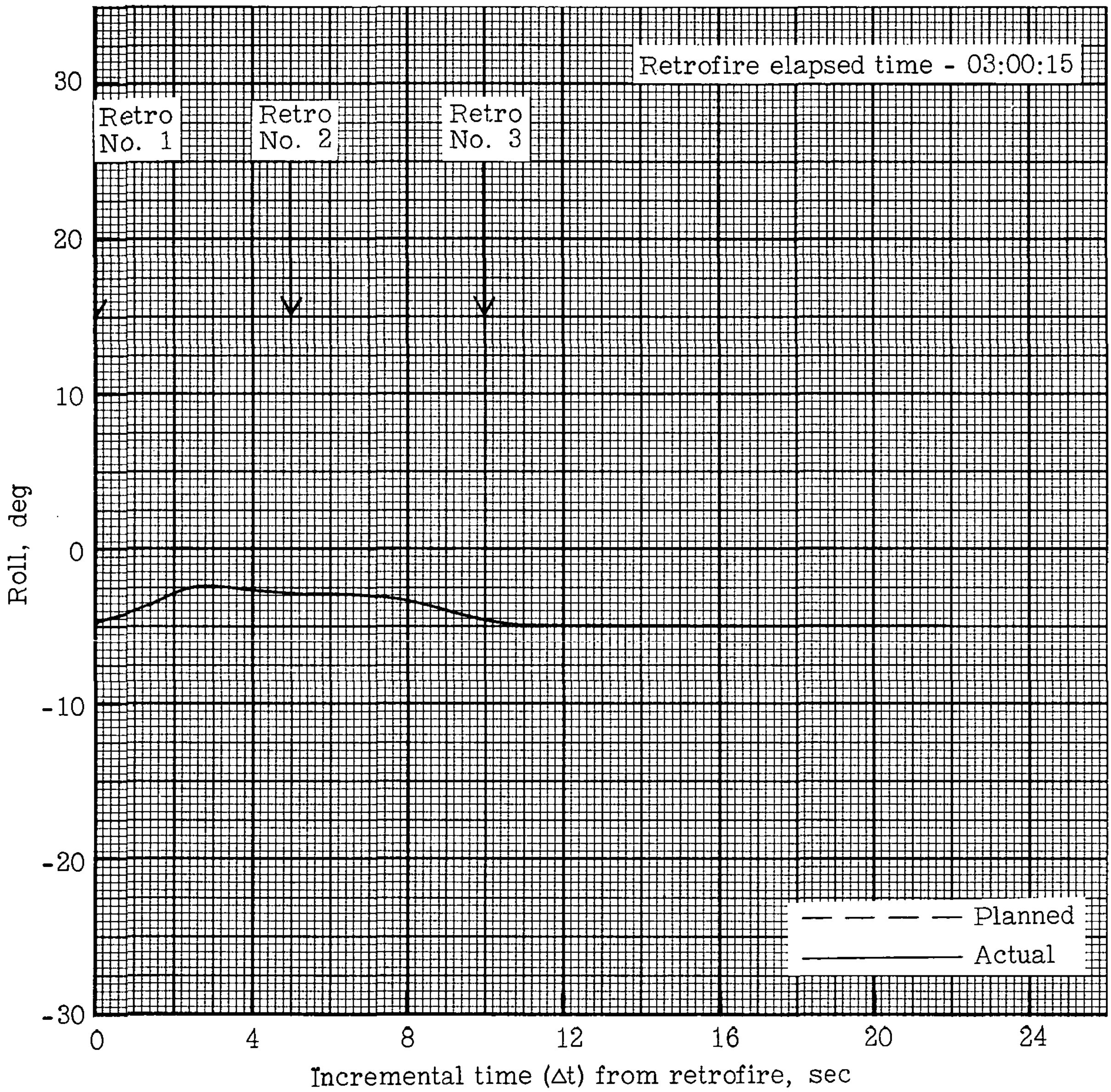
(a) Pitch angular attitude.

Figure 27. - Time history of capsule attitude during retrofire for the MA-5 mission compared with the nominal.



(b) Yaw angular attitude.

Figure 27. - Continued.



(c) Roll angular attitude.

Figure 27. - Concluded.

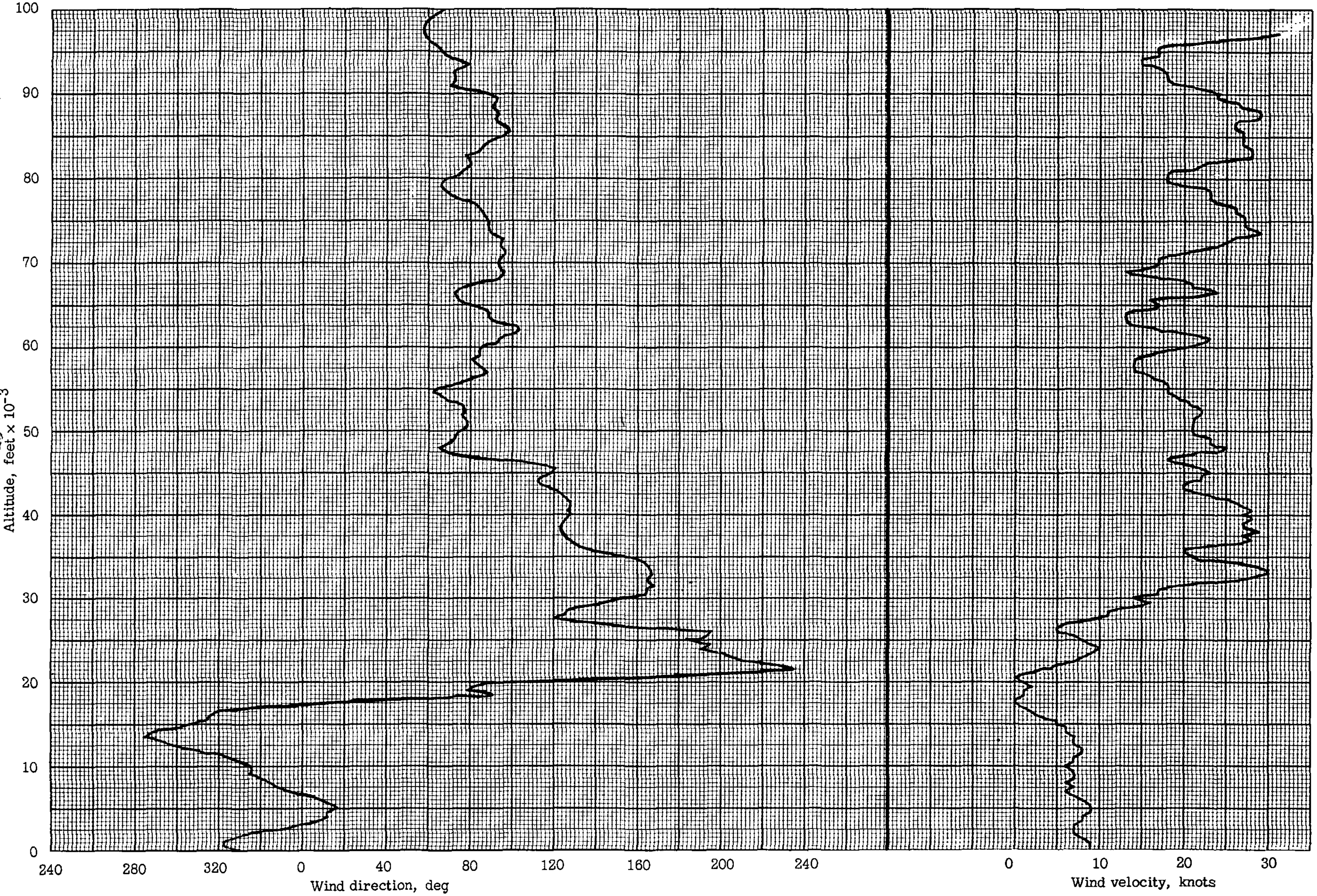


Figure 28. - Wind profile for MA-4 mission.

[redacted]

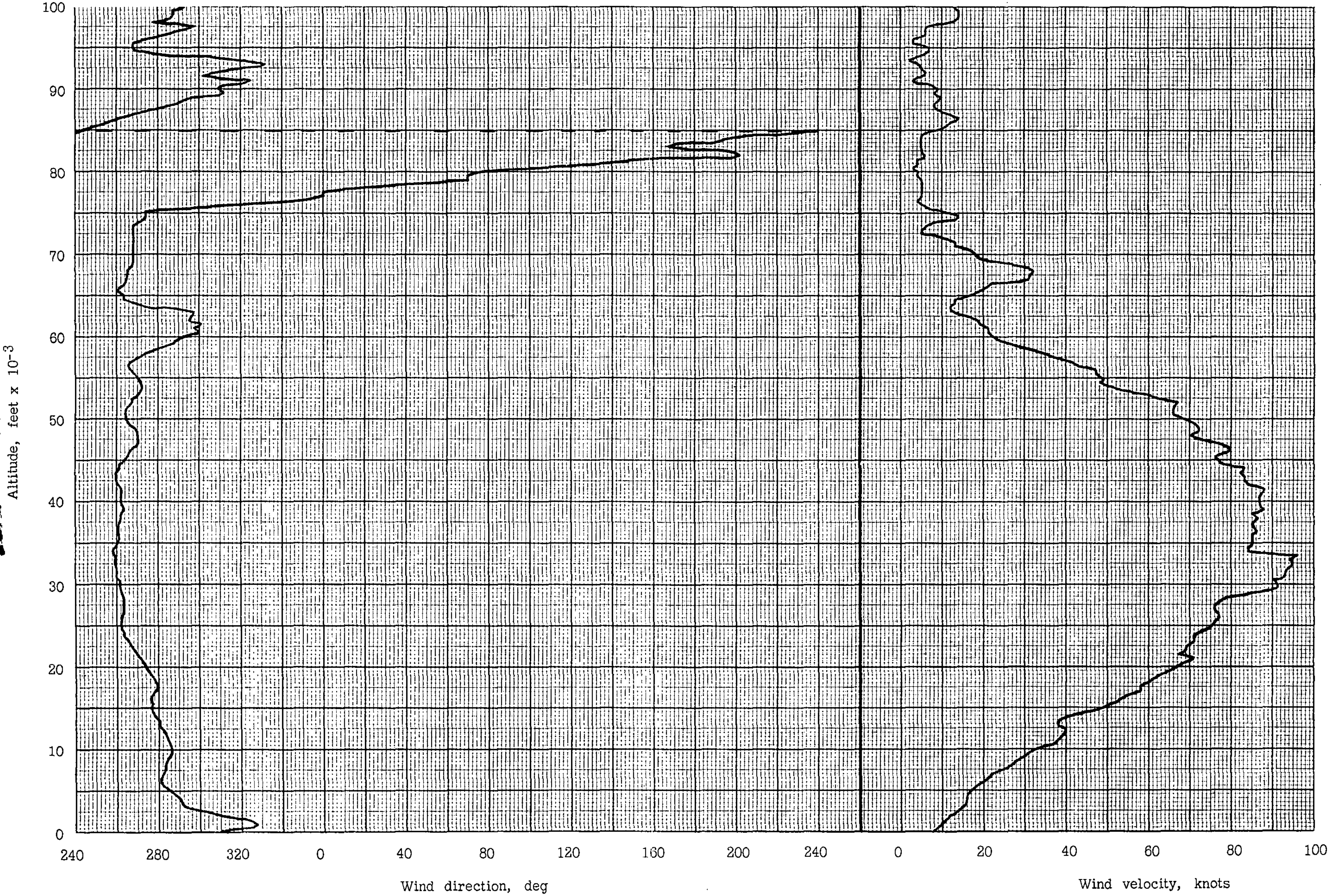


Figure 29. - Wind profile for MA-5 mission.

[redacted]

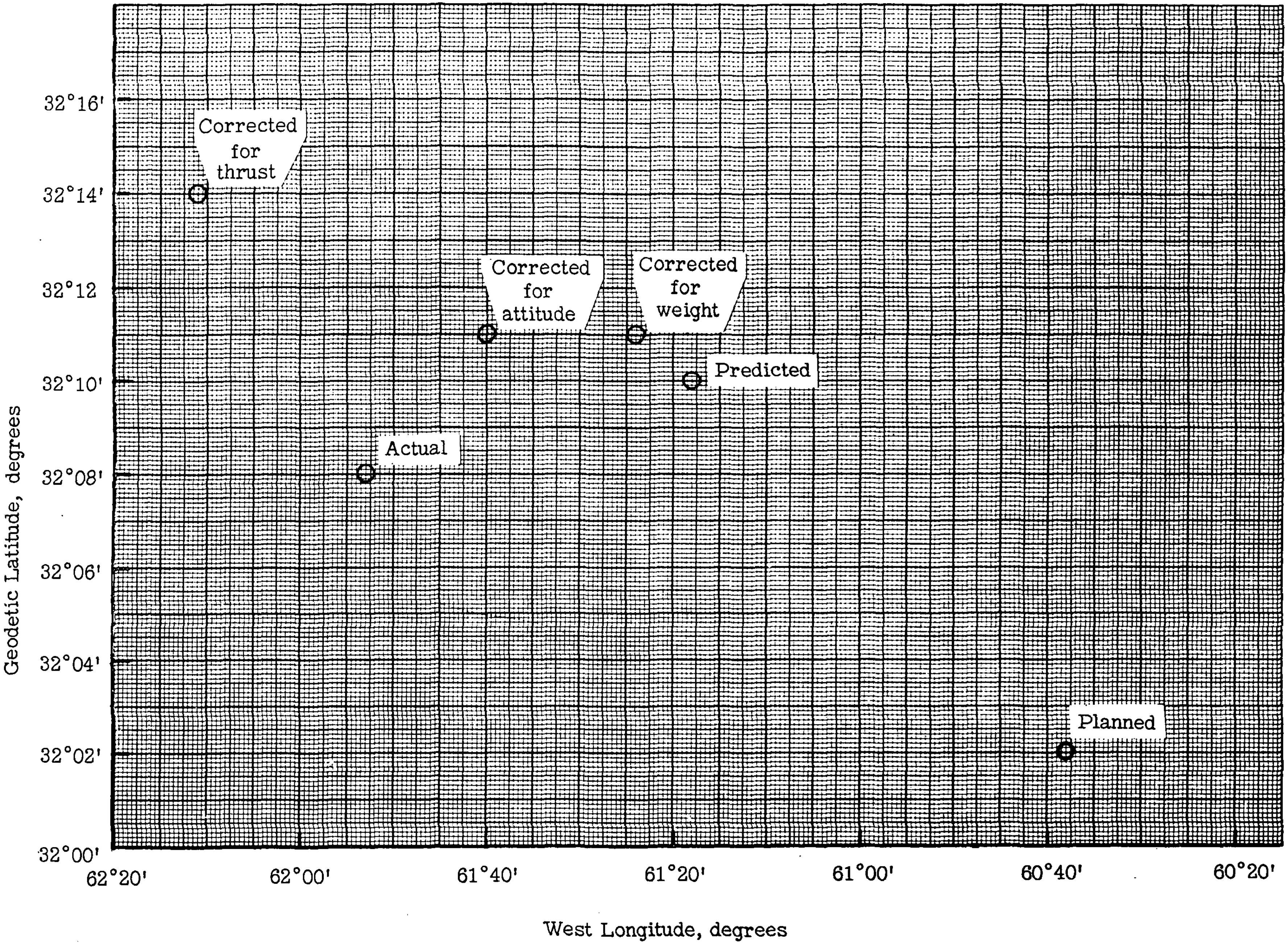


Figure 30. - Comparison of the actual and computed landing points for the MA-4 mission.

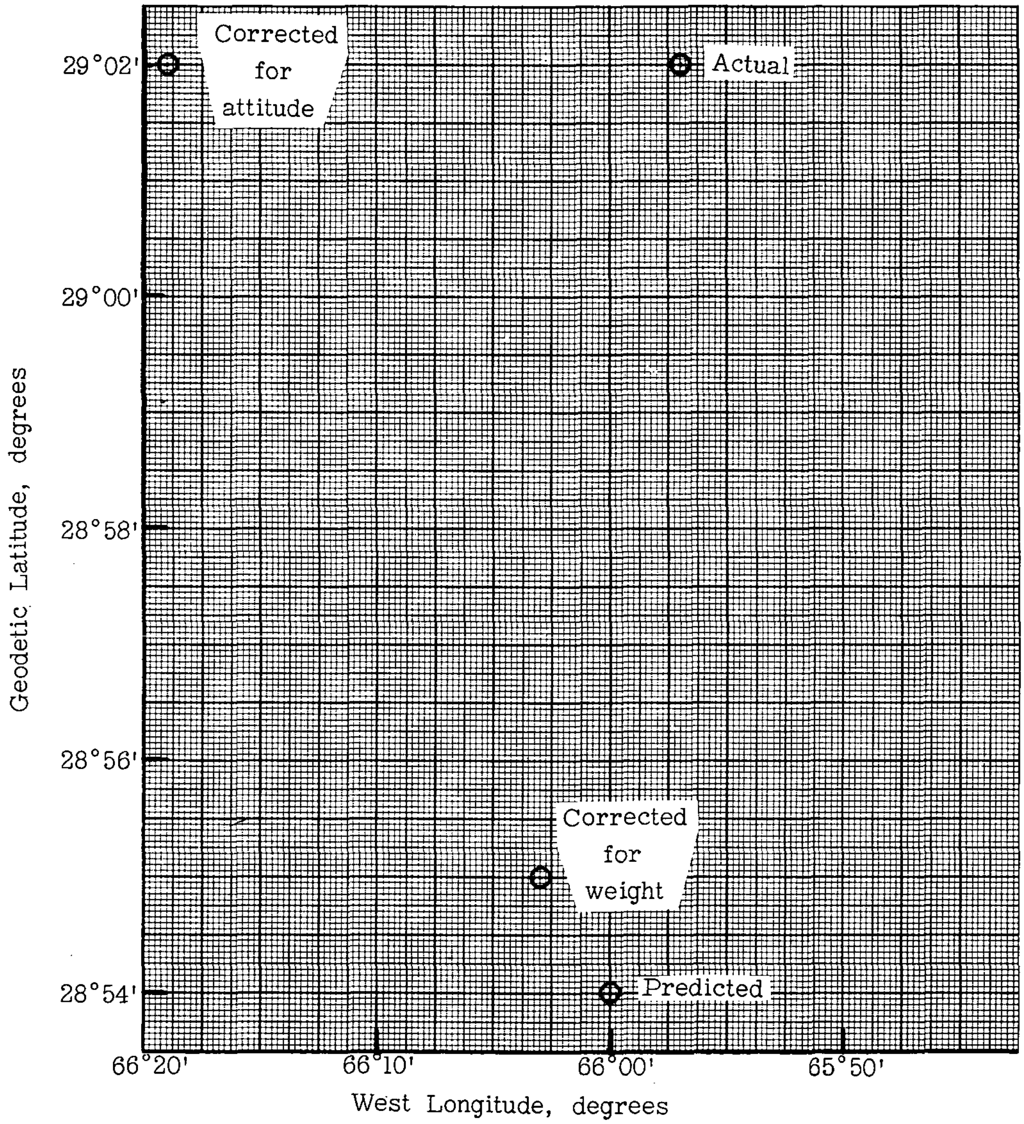


Figure 31. - Comparison of the actual and computed landing points for the MA-5 mission.